Guide to the Geology of the Lawrenceville Area

Lawrence and Crawford Counties, Illinois

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Field Trip Guidebook 1993D October 9, 1993

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Cover photo Pennsylvanian Bond Formation limestone, siltstone, and shale exposed along the south side of the Embarras River west of the 10th Street Bridge, Lawrenceville.

Geological Science Field Trips The Educational Extension Unit of the Illinois State Geological Survey conducts four free tours to acquaint the public with the rocks, mineral resources, and landscapes of various regions of the state and to discuss the geologic processes that led to their origin. Each field trip is an all-day excursion through one or more Illinois counties. Frequent stops are made to explore interesting sites, explain processes that shape our environment, discuss principles of earth science, and collect rocks and fossils. People of all ages and interests are welcome. The trips are especially helpful to teachers preparing earth science units. Grade school students are welcome, but each must be accompanied by a parent or guardian. High school science classes should be supervised by at least one adult for each ten students.

Field trip guide booklets are available for planning class tours and private outings. For a list, contact the Educational Extension Unit, Illinois State Geological Survey, Natural Resources Building, 615 East Peabody Drive, Champaign, IL 61820-6964. Call (217) 333-4747 or 244-2427.

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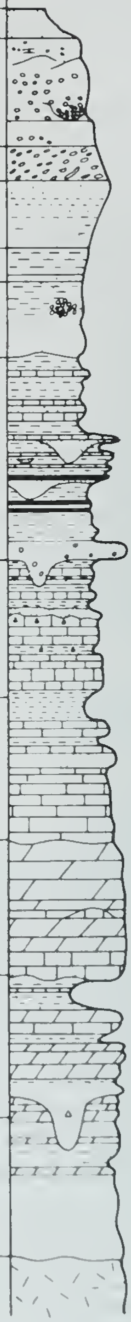
Era	Period or System and Thickness	Epoch	Age (years ago)	General Types of Rocks
CENOZOIC "Recent Life" — Age of Mammals		Holocene	10,000	Recent—alluvium in river valleys
	Quaternary 0-500'	Pleistocene Glacial Age	1.6 m.	Glacial till, glacial outwash, gravel, sand, silt, lake deposits of clay and silt, loess and sand dunes; covers nearly all of state except northwest corner and southern tip
	Tertiary 0-500'	Pliocene	5.3 m. – 36.6 m.	Chert gravel, present in northern, southern, and western Illinois
		Eocene	57.8 m.	Mostly micaceous sand with some silt and clay, present only in southern Illinois
		Paleocene	66.4 m.	Mostly clay, little sand; present only in southern Illinois
MESOZOIC "Middle Life" — Age of Reptiles	Cretaceous 0-300'		144 m. – 286 m.	Mostly sand, some thin beds of clay and, locally, gravel; present only in southern Illinois
PALEOZOIC "Ancient Life" — Age of Amphibians and Early Plants	Pennsylvanian 0-3,000' ("Coal Measures")		320 m.	Largely shale and sandstone with beds of coal, limestone, and clay
	Mississippian 0-3,500'		360 m.	Black and gray shale at base; middle zone of thick limestone that grades to siltstone, chert, and shale, upper zone of interbedded sandstone, shale, and limestone
PALEOZOIC — Age of Fishes	Devonian 0-1,500'		408 m	Thick limestone, minor sandstones and shales, largely chert and cherty limestone in southern Illinois; black shale at top
PALEOZOIC — Age of Invertebrates	Silurian 0-1,000'		438 m.	Principally dolomite and limestone
	Ordovician 500-2,000'		505 m	Largely dolomite and limestone but contains sandstone, shale, and siltstone formations
	Cambrian 1,500-3,000'		570 m	Chiefly sandstones with some dolomite and shale, exposed only in small areas in north-central Illinois
ARCHEOZOIC and PROTEROZOIC				Igneous and metamorphic rocks, known in Illinois only from deep wells



Generalized geologic column showing succession of rocks in Illinois.

LAWRENCEVILLE AREA

GEOLOGIC SETTING AND HISTORY

Lawrence and Crawford Counties lie along the eastern edge of southeast-central Illinois. Lawrenceville sits along the valley of the Embarras River near its confluence with the Wabash River. The field trip area includes the boundary between the northeastern part of the Mt. Vernon Hill Country and the Springfield Plain. *Tills** (fine grained silts and clays) deposited some 270,000 years ago during the Illinoian glacial stage mantle the bedrock. Wisconsinan-age gravels along the Wabash show that, as recently as about 12,500 years ago, the river was a major outlet for huge volumes of water released by the Wisconsinan *glaciers* melting away from areas farther to the north. Beneath the thin Pleistocene glacial materials lies *bedrock* deposited some 290 million years ago, which makes it upper Pennsylvanian in age. These *strata* include significant mineral deposits. Small strip mines have been operating in the region's shallow coal deposits recently. Lawrence County is one of the state's leaders in the production of crude oil. Oil wells in the county have produced some 430 million barrels from deeply buried rock of Pennsylvanian age and older. The field trip area, about 215 miles south of Chicago, nearly 130 miles southeast of Springfield, and some 145 miles northeast of Cairo, was the center of the highest oil production in Illinois in the early 1990s.

Bedrock

Through hundreds of millions of years, the Lawrence and Crawford County area underwent many changes. The ancient Precambrian *basement* composed of granitic *igneous*, and possibly *metamorphic*, crystalline rocks underwent deep erosion that resulted in a landscape similar to parts of the present Missouri Ozarks. In southernmost Illinois near what is now the Kentucky–Illinois Fluorspar Mining District, evidence from surface mapping, seismic exploration for oil, and measurements of Earth's gravitational and magnetic fields indicates that rift valleys like those in east Africa formed during a period when plate *tectonic* movements were beginning to rip apart the early North American continent. These rift valleys, now referred to as the Rough Creek Graben and the Reelfoot Rift, filled with sands and gravels shed from the adjacent uplands, and with *sediments* deposited in lakes that formed along the valley floors.

Around the begining of the Paleozoic *Era*, some 525 million years ago, the rifting stopped and the hilly Precambrian landscape began to slowly sink on a broad, regional scale. This permitted the invasion of a shallow sea from the south and southwest. During the several hundred million years of the Paleozoic Era, the area that is now southern Illinois sank periodically, allowing shallow seas to ebb and flood across it. At times, however, the seas withdrew, and the sediments they had deposited were subjected to weathering and erosion. As a result, the *sedimentary* record has some gaps. By the end of the Paleozoic Era about 245 million years ago, at least 15,000 feet of sedimentary strata had accumulated (figs. 1 and 2). The Paleozoic strata range from about 523 million years old (Cambrian *Period*) to 288 million years old (Pennsylvanian Period). The bedrock geologic map shows the lateral occurrence of these rocks in Illinois below the surface deposits (fig. 3). As indicated by evidence from outcrops and drill holes elsewhere in Illinois, younger rocks of latest Pennsylvanian and perhaps Permian (the youngest Paleozoic rocks) or even younger age may once have been deposited in this area. During the 245 million years between the close of the Paleozoic Era and the onslaught of glaciation nearly 2 million years ago, however, ample time passed for the erosion of perhaps thousands of feet of strata. All traces have been erased of any post-Pennsylvanian rocks that may have been present. Indirect evidence based on the rank of coal deposits and the generation of petroleum from source rocks indicates that latest Pennsylvanian and younger rocks as much as 1½ mile thick once covered southern Illinois. In the field

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* Words in *italics* are defined in the glossary at the back of the guidebook. Also please note: although Lawrence and Crawford Counties, Illinois, and all present localities have only recently appeared within the geologic time frame, we use the present names of places and geologic features because they provide clear reference points for describing the ancient landscape.

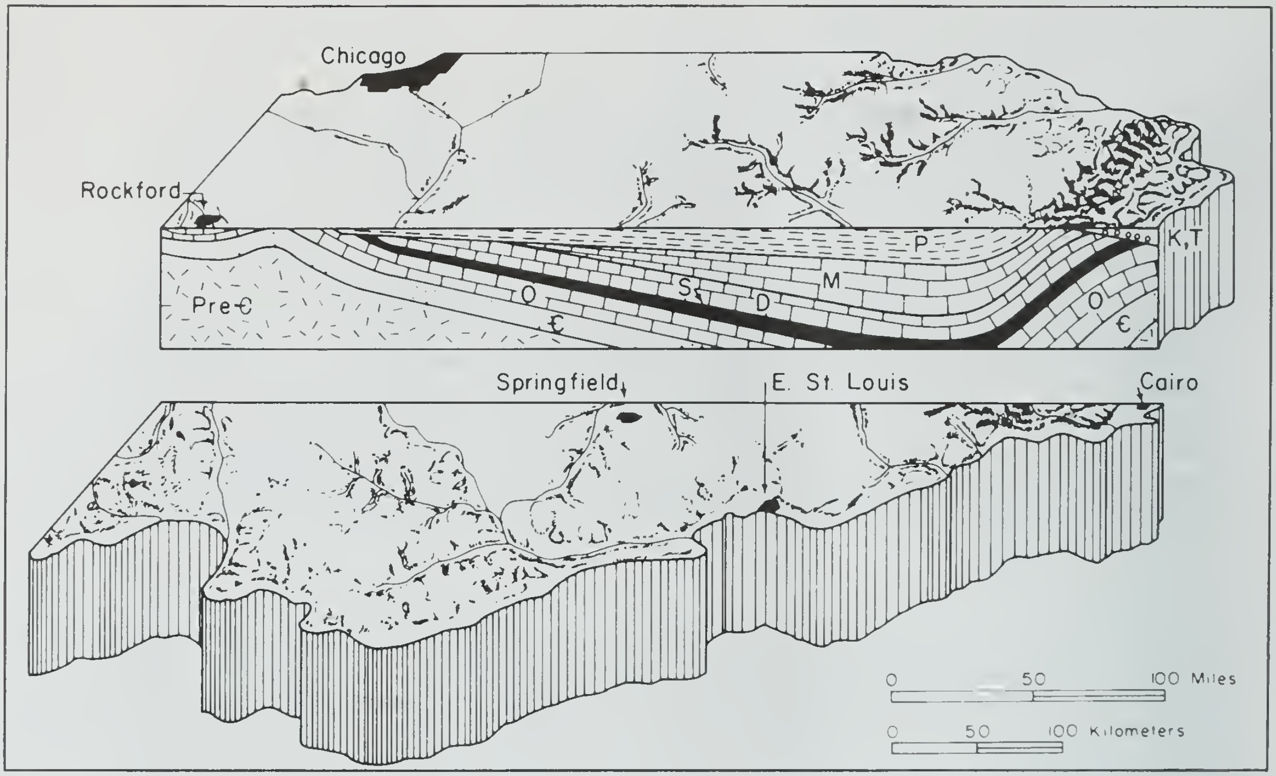


Figure 1 Stylized north-south cross section shows the structure of the Illinois Basin. The thickness of the sedimentary rocks has been greatly exaggerated to show detail; younger, unconsolidated surface deposits have been eliminated. The oldest rocks, Precambrian (Pre-C) granites, form a depression filled with layers of sedimentary rocks of various ages: Cambrian (C), Ordovician (O), Silurian (S), Devonian (D), Mississippian (M), Pennsylvanian (P), Cretaceous (K), and Tertiary (T). Scale is approximate.

trip area today, Paleozoic sedimentary strata reach thicknesses of about 9,400 feet in the north and about 10,500 feet in the west. Rocks of the Devonian, Mississippian, and Pennsylvanian Periods have been successfully drilled for their petroleum resources in Lawrence and Crawford Counties (figs. 2 and 4).

Bedrock strata of Pennsylvanian age lie immediately beneath a cover of glacial till and consist of sandstone, siltstone, shale, *limestone*, coal, and underclay deposited in shallow seas and swamps between about 320 and 288 million years ago. Some of these rocks are exposed in scattered road and stream cuts. Producing oil fields have been developed in Pennsylvanian sandstones of both counties. The thickness of Pennsylvanian strata increases westward from slightly less than 1,200 feet near the Wabash River to about 2,000 feet along the western boundaries. A description of these rocks and their occurrence may be found in *Depositional History of the Pennsylvanian Rocks* (at the back of the guide booklet).

Structural and Depositional History

Near the close of the Mississippian Period (320 million years ago), gentle arching of the rocks in eastern Illinois initiated the development of the La Salle Anticlinal Belt (fig. 5). An *anticline* is a geologic term for a hill or *dome* in which the rock layers have been bent into an arch. The La Salle Anticlinal Belt is a complex structure having smaller structures such as domes, anticlines, and *synclines* superimposed on the broad upwarp of the belt. This gradual arching continued through Pennsylvanian time. The youngest Pennsylvanian strata are absent from the area of the anticlinal belt, either because of nondeposition or erosion, so we cannot know just when

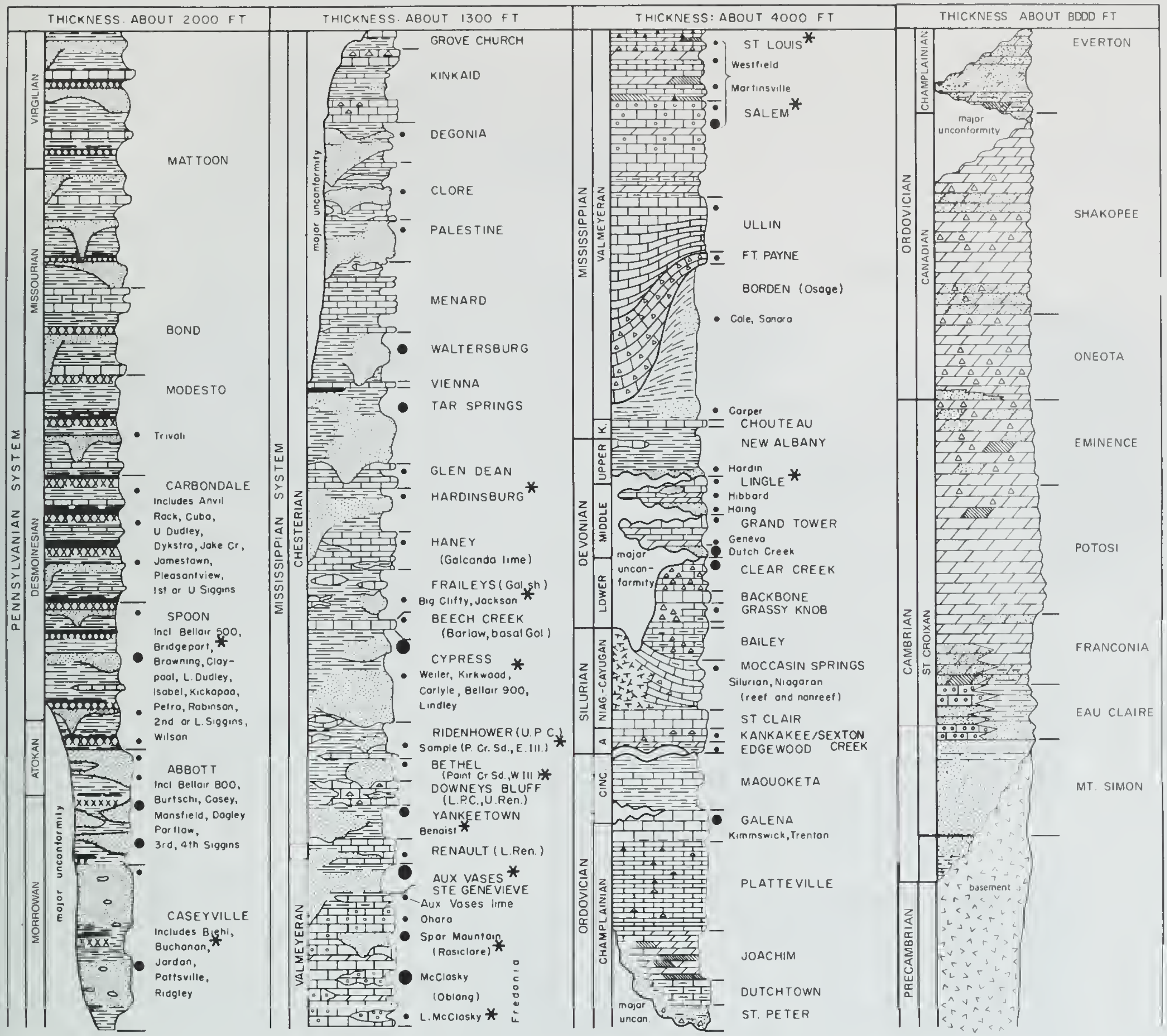


Figure 2 Generalized stratigraphic column of the southern Illinois Basin. Black dots indicate oil and gas pay zones (variable vertical scale) (from Leighton et al. 1991). ✱ *Main pay zones in Lawrence Field.*

movement along the belt ceased—perhaps by the end of the Pennsylvanian or a little later near the close of the Paleozoic Era during the Permian Period.

After the Paleozoic Era, during the Mesozoic Era, the rise of the Pascola Arch (fig. 6) in southeastern Missouri and western Tennessee separated the Illinois Basin from other basins to the south. The Illinois Basin is a broad downwarp covering much of Illinois, southern Indiana, and western Kentucky (figs. 1 and 6). Development of the Pascola Arch in conjunction with the earlier sinking of the deeper parts of the Illinois Basin gave the Illinois Basin its present asymmetrical, spoon-shaped configuration.

The Lawrenceville field trip area is located on the eastern flank of the Illinois Basin and the southeastern end of the La Salle Anticlinal Belt. Bedrock strata dip southwestward into the basin. Because tilting of the bedrock layers took place several times during the Paleozoic Era, the dips of successive strata are not parallel to one another.

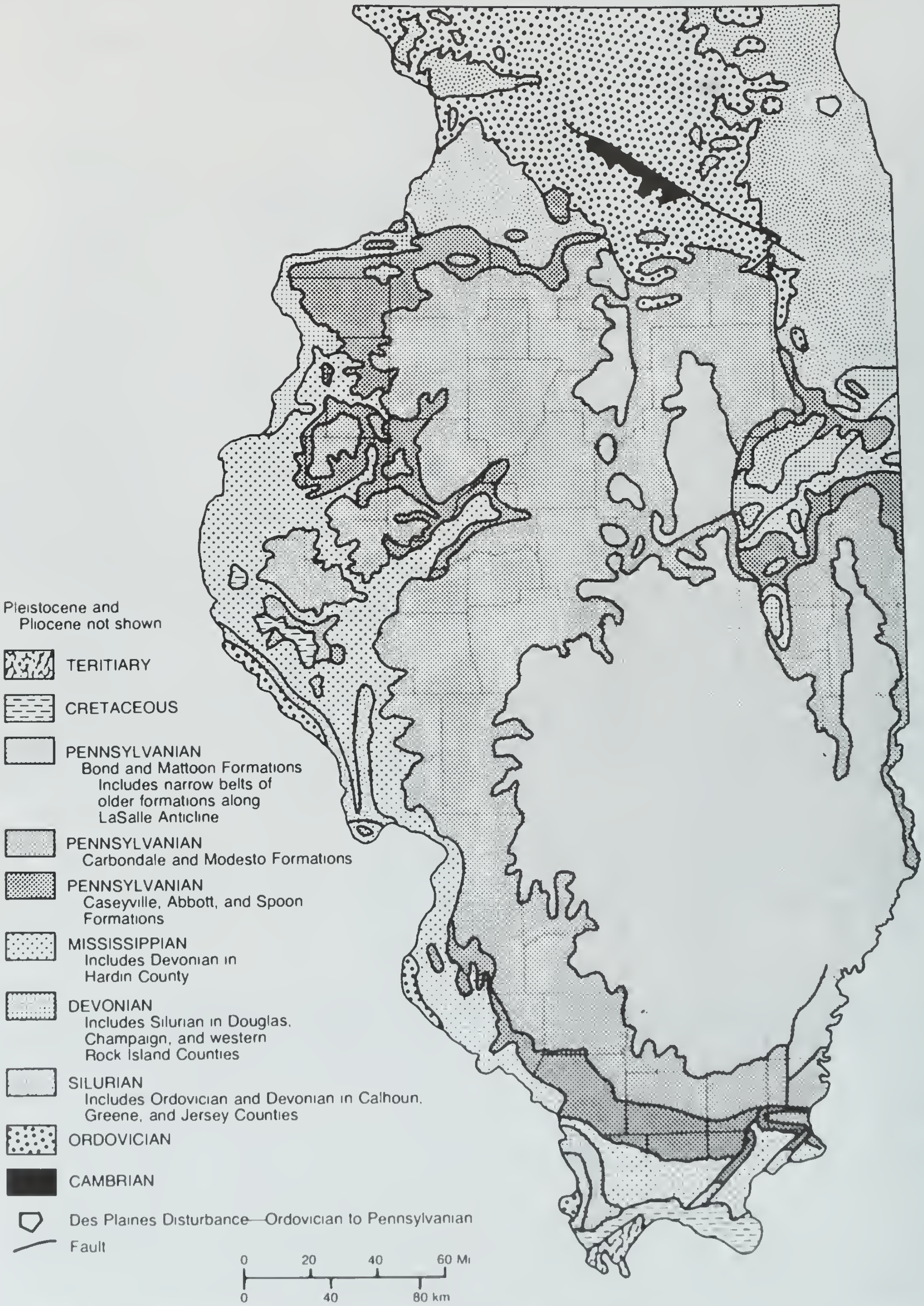


Figure 3 Bedrock geology beneath surficial deposits in Illinois.

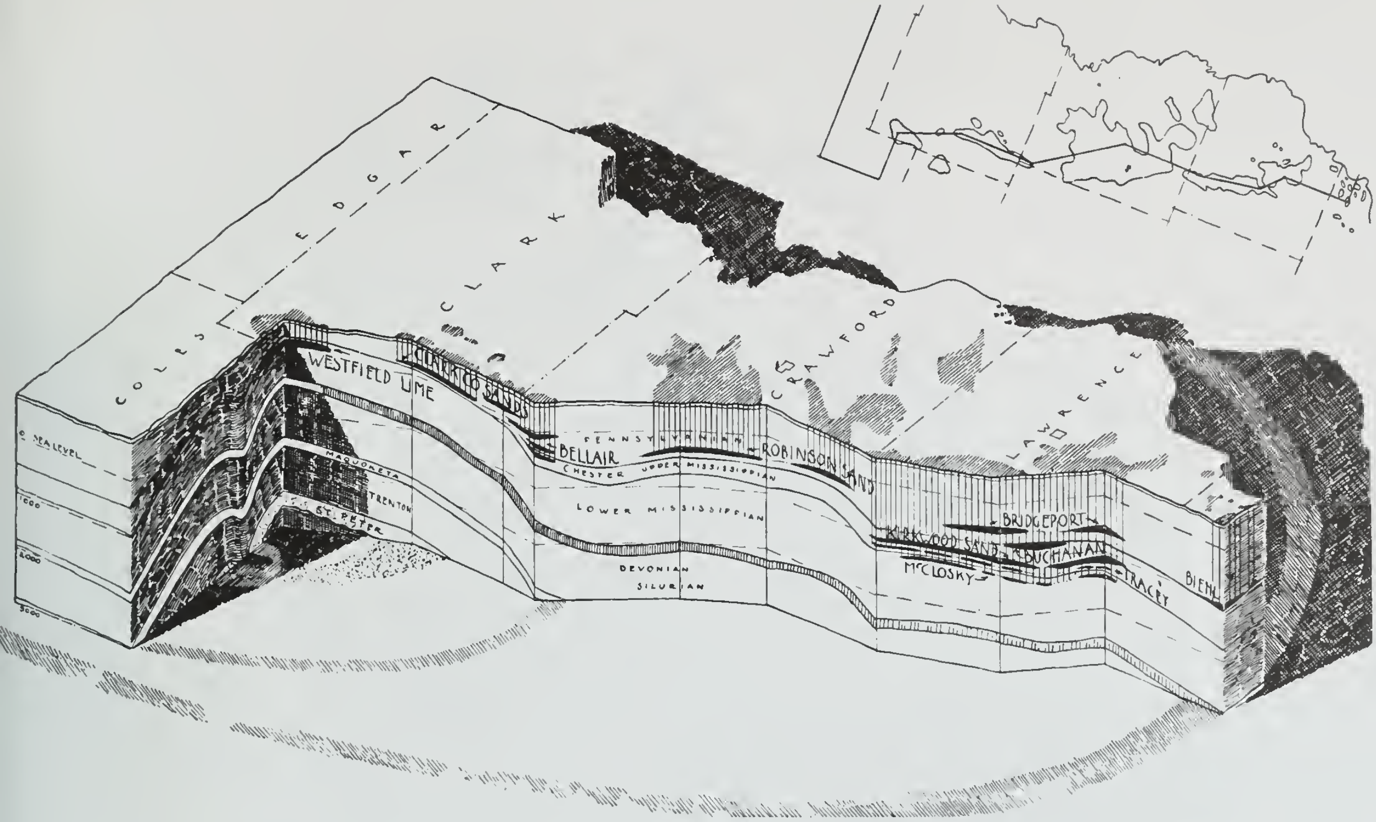


Figure 4 Block diagram shows the generalized structure and thicknesses of the Paleozoic rock layers in the region around the field trip area. Outlines of the old southeastern Illinois oil fields are shown by hatching on the surface of the block. Approximate locations of the oil-producing rock layers, or pay zones, are shown by named, black lenses along the side of the block (from ISGS Circular 110, 1944).

Glacial History

The *topography* of the bedrock surface through much of Illinois is largely hidden from view by glacial deposits, except where strata are exposed along the major streams. In many areas, the glacial *drift* is thick enough to completely mask the underlying bedrock surface. Water well logs and other drill hole information, coupled with scattered bedrock exposures in some stream valleys and roadcuts, show that the field trip area lies in a region in which the present land surface largely reflects the underlying bedrock surface. Thus, the preglacial bedrock surface has been only slightly modified and subdued by a thin mantle of glacial drift. (A brief general history of glaciation in North America and a description of the deposits commonly left by glaciers may be found in the section, *Pleistocene Glaciations in Illinois,* at the back of the guide booklet.)

The area covered by the Lawrenceville field trip in southeast-central Illinois was repeatedly buried under massive, slow moving, continental glaciers or *ice sheets* during the geologically recent Ice Age. This period, known as the Pleistocene *Epoch*, lasted in Illinois from at least 1.6 million years until about 10,000 years before the present (B.P.). Glaciers may have first covered the area about 700,000 years B.P. during pre-Illinoian time; and the last ice sheet melted from the northern part of the field trip area about 190,000 years B.P. at the end of the Monican advance (Illinoian) (see *Pleistocene Glaciations in Illinois,* at the back of the guide booklet).

Ice sheets covered the state several times during the Illinoian Glacial Stage from perhaps 300,000 to 175,000 years B.P. During Illinoian time, North American continental glaciers reached their southernmost extent, after advancing from Canada as far as the northern part of Johnson County about 100 miles southwest of Lawrenceville (fig. 7). Although the Illinoian glaciers built morainic ridges similar to those of later Wisconsinan glaciers, Illinoian *moraines* are apparently

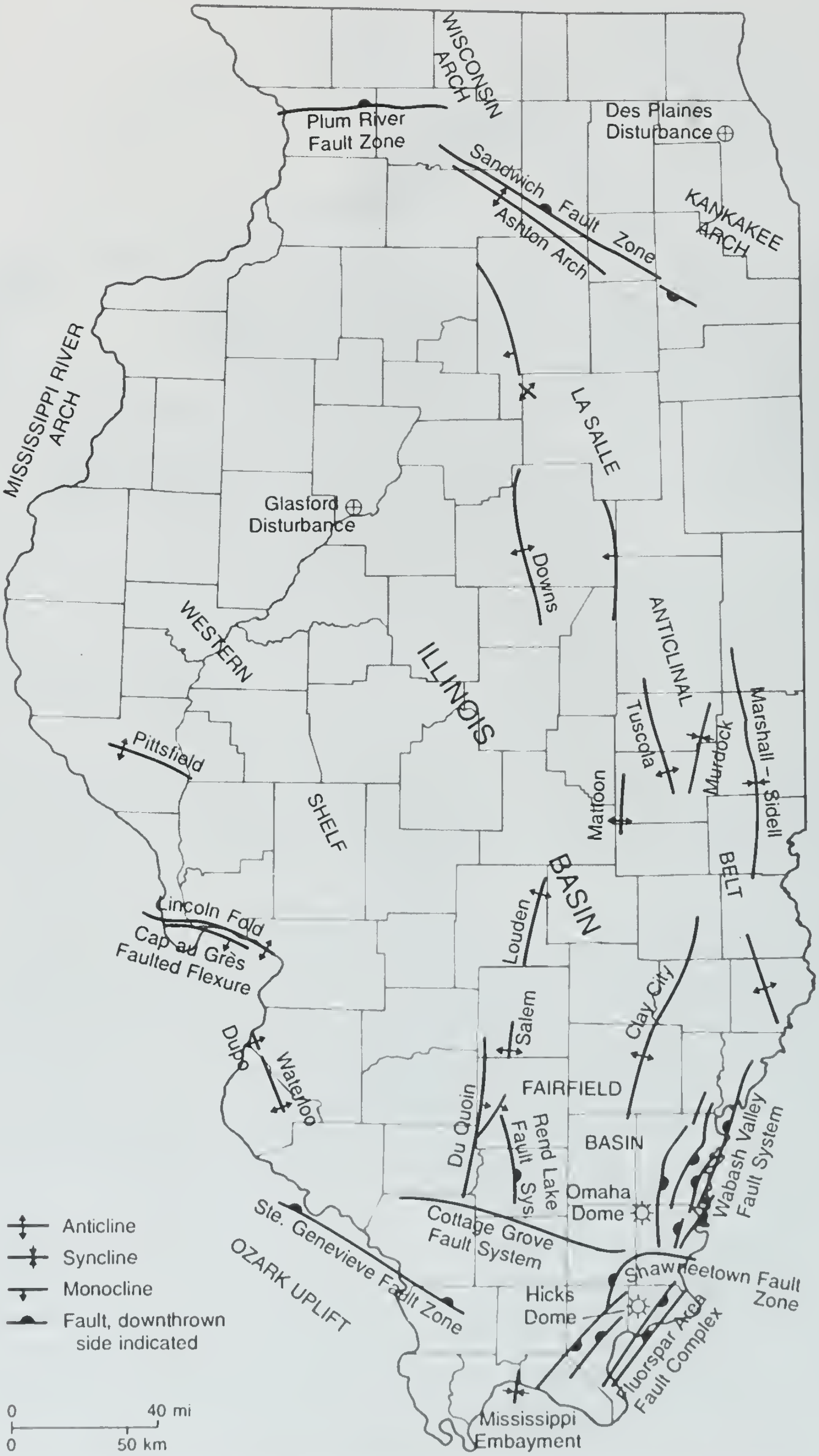


Figure 5 Major geologic structures of Illinois (compiled by J. Treworgy, 1979).

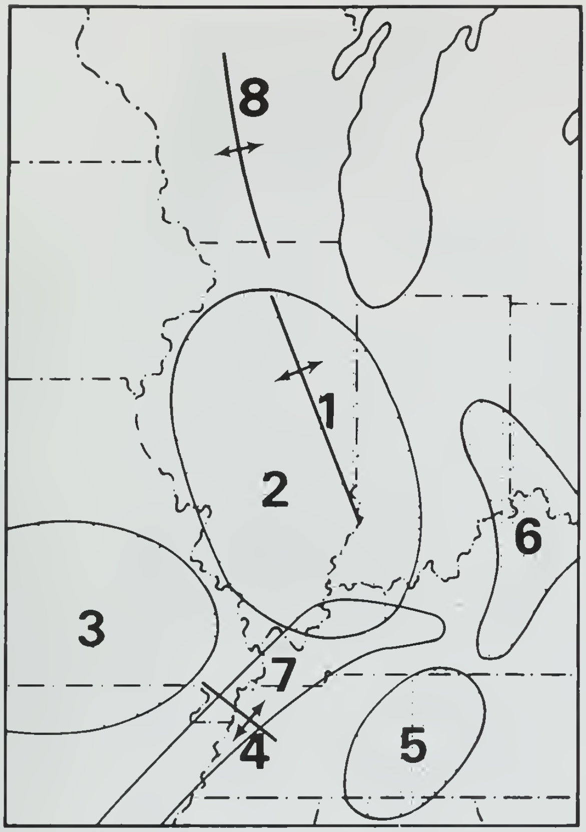


Figure 6 Some major structures in the Illinois region: (1) La Salle Anticlinal Belt, (2) Illinois Basin, (3) Ozark Dome, (4) Pascola Arch, (5) Nashville Dome, (6) Cincinnati Arch, (7) Rough Creek Graben–Reelfoot Rift, and (8) Wisconsin Arch.

not so numerous. They have been exposed to weathering and erosion for thousands of years longer than their younger Wisconsinan counterparts; consequently, their topographic expression is generally more subdued.

The northernmost point of the Lawrenceville field trip area is about 38 miles southeast of the southernmost point reached some 20,000 years B.P. by the younger Woodfordian continental glaciers (Wisconsinan Stage). Although these ice sheets did not reach the Lawrenceville area, wind-blown silt or *loess* (pronounced "luss") of late Wisconsinan age blankets the poorly sorted till or ground moraine (glacial drift) left behind by the Illinoian and pre-Illinoian glaciers. Loess thickness ranges from about 3 feet to a little more than 10 feet near the Wabash River; however, in some places, especially near some streams, erosion has removed all but a few inches. The highly productive soils that cover much of Illinois were formed by the weathering of these extensive loess deposits over several thousands of years after the melting of the last glaciers.

Physiography

The Lawrenceville field trip area is situated in the northeastern part of the Mt. Vernon Hill Country, the southernmost division of the Till Plains Section, Central Lowland Province in Illinois (fig. 8). The Mt. Vernon Hill Country is essentially a bedrock-controlled region in which most of the gently rolling, preglacial bedrock surface is generally only thinly mantled with glacial drift. The region has a mature topography of low relief with limited upland prairies and broad alluviated valleys along the larger streams. Glacial landforms are either uncommon or difficult to recognize because they have been subjected to weathering for tens of thousands of years. Furthermore, any landforms built by Illinoian glaciers have been mantled with loess of varying thicknesses.

Apparently, just before the advent of glaciation, an extensive system of *bedrock valleys* was deeply entrenched below the ancient Illinois land surface. As glaciation began, streams probably

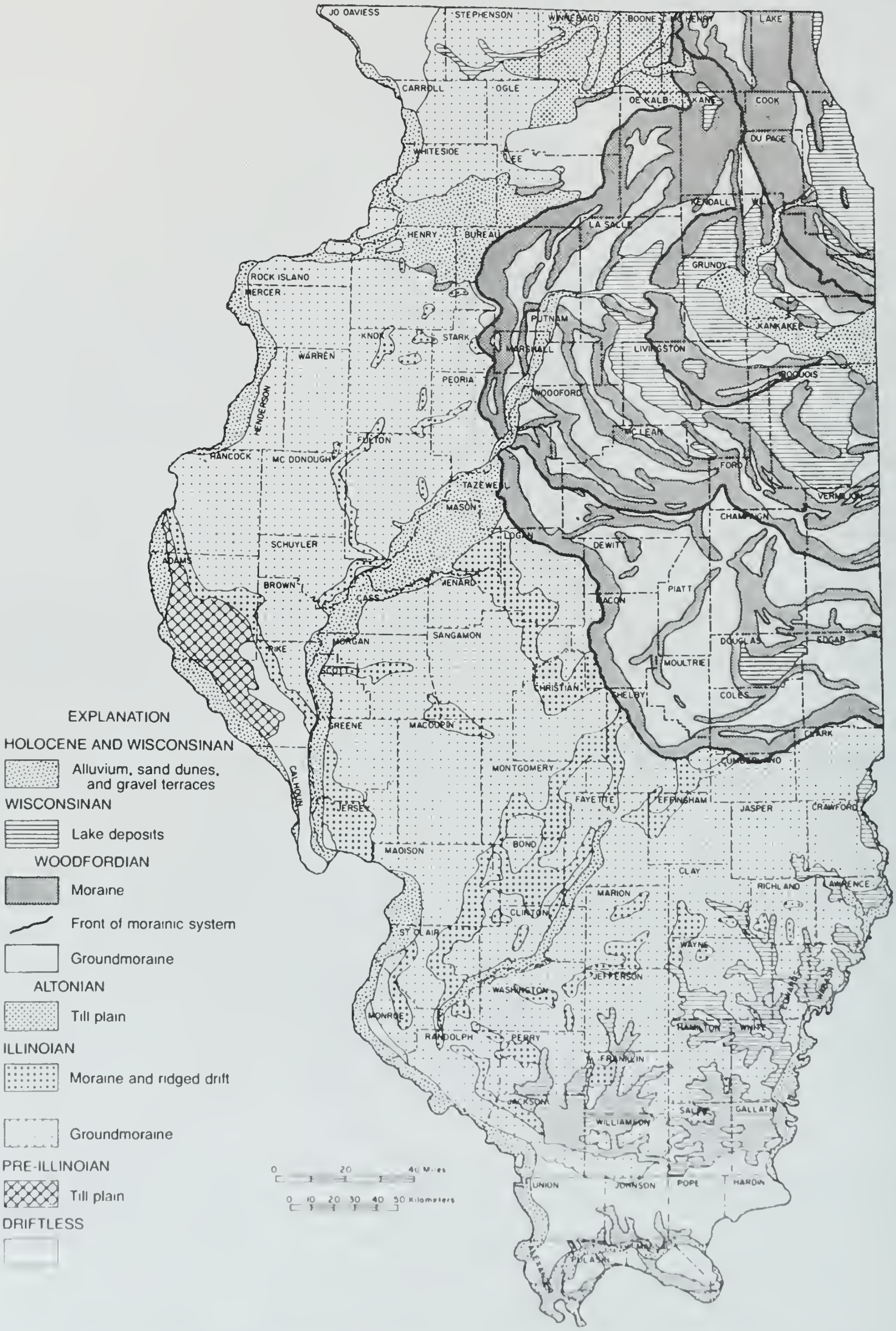


Figure 7 Generalized map of glacial deposits in Illinois (modified from Willman and Frye 1970)

Figure 8 Physiographic divisions of Illinois.

changed from erosion to aggradation; that is, the streams began to build up and fill in their channels because they did not have sufficient volumes of water to carry and move the increased quantities of sediments. To date, no evidence indicates that the early fills in these preglacial valleys were ever completely flushed out of their channels by meltwater torrents during the succeeding deglaciation.

Drainage

The present drainage system is relatively complete. Most streams have broad terraced valleys and low gradients (bottom slopes). The uplands generally have good natural drainage, but the larger valley bottoms are poorly drained. The Embarras River (pronounced "Ambraw"), the major tributary to the Wabash in the field trip area, flows south-southeast for more than 95 miles from the Champaign–Urbana area to join the Wabash River about 7 miles southeast of Lawrenceville. The Embarras is a very sluggish stream during most of the year and meanders widely across its valley. Muddy Creek is the main tributary to the Embarras in the field trip area. To the north in Crawford County, Brushy and Sugar Creeks and their smaller tributaries drain southeast to the Wabash. The larger streams are sluggish and occupy preglacial bedrock valleys for the most part. Ditches have been dug across the wide valley bottoms to facilitate drainage there.

Relief

The highest land surface along the field trip route is the crest of Red Hill (mile 22.6+) in Red Hills State Park, where the surface elevation is slightly more than 630 feet above mean sea level (msl). The lowest elevation is less than 410 feet msl at the Stop 7 site on the Embarras River, during low water. The surface relief of the field trip area, calculated as the difference between the highest and lowest surfaces, is about 230 feet. *Local relief*, although generally 50 to 70 feet, is highest at Red Hills State Park west of Lawrenceville, where it is nearly 190 feet.

MINERAL PRODUCTION

Of the 102 counties in Illinois, 98 reported mineral extraction during 1990, the last year for which complete records are available. (Note: stone production is reported for the odd-numbered years, and sand and gravel production is reported for the even-numbered years). Estimates for the total stone production for 1989 are included in the total value given for mineral production. The total value of all minerals extracted, processed, and manufactured in Illinois during 1990 was $2,915,000,000, a 2.5% increase over the total value recorded in 1989 (Samson 1992). In Illinois, the leading commodity continued to be coal, followed by oil, stone, sand and gravel, and clays. Illinois maintained its lead over other states in production of fluorspar, industrial sand, and tripoli.

In 1990, Illinois ranked fifth in the nation in coal production; 61.7 million tons of coal, valued at $1,709.8 million, was mined. Production of nearly 20 million barrels of crude oil, valued at $406.5 million, placed Illinois 13th among the oil-producing states. The less than 0.7 million cubic feet of natural gas produced in the state during 1990 was valued at nearly $1.5 million. In 1989, the latest year for which data are available, total Illinois stone production was estimated to be 62.7 million tons, valued at $283.1 million; reported tonnage placed Illinois fourth among 48 states reporting production of crushed and broken stone. In the 54 Illinois counties that produced stone, 103 companies operated 178 quarries. Stone is used primarily for construction aggregate, especially as road-base stone, but it is also used in chemical and agricultural production. Illinois ranked seventh in the production of sand and gravel during 1990; total extraction amounted to 32.4 million tons valued at $104.7 million at the pit, equivalent to an average estimated unit value of $3.23 per ton. Because of its relatively low unit price, it is not economical to ship most construction sand and gravel more than about 50 miles from the pit, although operations along navigable rivers may permit shipment for much greater distances. In 1990, 105 companies operated 144 sand and gravel pits at 143 operations in 55 counties.

Lawrence County ranked 18th among the counties in the value of its mineral production during 1990. Crude oil and sand and gravel were the mineral commodities extracted. Cumulative crude oil production from 1888 to 1990 amounted to 425,593,000 barrels. During 1990, a total of 2,565,000 barrels of oil valued at $52,244,000 was produced, ranking Lawrence County first with 12.9% of the state's total production. No coal production was reported for the county.

Crawford County ranked 15th among the counties in the value of its mineral production during 1990. Crude oil and sand and gravel were extracted. In addition, sulfur was processed and clay products were manufactured. Cumulative crude oil production from 1888 to 1990 amounted to 253,596,000 barrels. During 1990, a total of 2,072,000 barrels of oil valued at $42,214,000 was produced, ranking Crawford County second with 10.4% of the state's total production. The cumulative total of coal produced from surface mines from 1833 to 1990 amounted to 17,315 tons. The cumulative total of coal produced from 1833 to 1990 amounted to 45,400 tons.

Construction sand and gravel sources are found mainly in glacial deposits, chiefly *valley trains*. For reporting purposes, the state has been divided into four districts. The southernmost District 3 comprises 14 producing counties, including Lawrence and Crawford. The 22 companies that operated 23 pits extracted 2,569,000 tons of sand and gravel valued at some $7,328,000.

GROUNDWATER

Groundwater is a mineral resource frequently overlooked in assessing the natural resource potential of an area. The availability of this mineral resource is essential for orderly economic and community development. More than 48% of the state's 11 million citizens depend on groundwater for their water supply.

Groundwater is derived from underground formations called *aquifers*, located in the zone of saturation. An aquifer is a body of water-bearing materials that are porous and permeable enough to release usable quantities of water into an open well or spring. The water-yielding capacity of an aquifer can only be evaluated by constructing wells into it. After construction, the wells are pumped to determine the quality and quantity of groundwater available for use.

The bottomlands and partially buried valleys of the Embarras and Wabash Rivers contain thick deposits of permeable sand and gravel that can yield adequate water supplies for municipal and industrial purposes. Data on available groundwater sources in the county indicate that not only are the glacial sand and gravel deposits along and in the Embarras and Wabash Valleys the most productive and accessible of the various systems, but they also have a high natural recharge rate because they extend to the land surface in many areas. Under the uplands, however, sand and gravel stringers in the glacial drift are thin and discontinuous, and thus cannot yield water for more than domestic or farm purposes. Aquifers, especially those exposed at the surface or overlain by very thin cover, are susceptible to pollution from agricultural and urban land use and waste-disposal activities. Increased irrigation from shallow aquifers in areas of thick surficial sands and gravels in combination with heavy fertilizer applications can lead to degradation of these aquifers.

Some Pennsylvanian sandstones can yield adequate quantities of water for domestic or farm use. Although some of this water is highly mineralized, there are areas where it appears to be relatively pure. Drilling and testing are necessary to locate an adequate potable source of water.

GUIDE TO THE ROUTE

Assemble at Lawrenceville High School, 8th and Charles Streets, about two blocks northeast of the courthouse. Park your vehicle in line so that the caravan can start out immediately after registration.

You must travel in the caravan. *Do not drive ahead of the caravan!* Please keep your headlights on while in the caravan. Drive safely but stay as close as you can to the car in front of you. Please obey all traffic signs. If the road crossing is protected by a guard vehicle with flashing lights and flags, then obey the signals of the ISGS staff member directing traffic. When we stop, park as close as possible to the car in front of you and turn off your lights.

Some stops on the field trip are on private property. The owners have graciously given us permission to visit on the day of the field trip only. Please conduct yourselves as guests and obey all instructions from the trip leaders. So that we may be welcome to return on future field trips, please do not litter or climb on fences. Leave all gates as you found them. These simple rules of courtesy also apply to public property. If you use this booklet for a field trip with your students, youth group, or family, you must get permission (because of trespass laws and liability constraints) from property owners or their agents before entering private property.

Ready, get set, go! Start calculating your mileage at the southeast corner of Lawrenceville High School at the intersection of Charles and 8th Streets (about 750 feet from NE line and 1,175 feet from SE line, Tract 5 or E½ NE NE NW, Section 6, T3N, R11W, 2nd Principal Meridian [P.M.], Lawrence County; Lawrenceville 7.5-Minute Quadrangle [38087F6]*).

Miles to next point	Miles from start	
0.0	0.0	HEAD SOUTH on 8th Street.
0.1+	0.1+	STOP: (1-way) at theT-intersection with State Street. TURN RIGHT (west) and prepare to turn left at the next corner.
0.05	0.15	TURN LEFT (south) on 9th Street.
0.05+	0.2+	STOP: (2-way) at Jefferson Street. CONTINUE AHEAD (south).
0.1+	0.3+	STOP: (2-way) at Lexington Avenue. TURN RIGHT (west).
0.15+	0.45+	STOP: (4-way) at 12th Street. CONTINUE AHEAD (west).
0.2+	0.7+	CAUTION: stop light at 15th Street and State route (SR) 1. CONTINUE AHEAD (west).
0.05+	0.75+	BEAR LEFT (southwest) on Porter Avenue at inverted "r" intersection.
0.15	0.9+	STOP: (4-way). CONTINUE AHEAD (southwest).

* The number in brackets following the topographic map name, [38087F6], is the code assigned to that map as part of the National Mapping Program. The state is divided into 1É blocks of latitude and longitude. The first pair of numbers refers to the latitude of the southeast comer of the block and the next three numbers designate the longitude. The blocks are divided into 64 7.5-minute quadrangles; the letter refers to the east-west row from the bottom, and the last digit refers to the north-south column from the right.)

0.4	1.3+	CAUTION: crossroad (1030N, 1140E). Pavement ends. CONTINUE AHEAD (southwest) on the oil and chip road.
0.5	1.8+	Pipeline crossing.
0.25+	2.05+	CAUTION: T-road from left (1000N, 1070E). CONTINUE AHEAD and prepare to stop.
0.05+	2.1+	PARK along the shoulder as far off the road as you safely can. WATCH for traffic.

STOP 1 Oil refinery and tank farm lie to the east-southeast (NW corner, NE NE NW NE extended, Section 11, T3N, R12W, 2nd P.M., Lawrence County; Lawrenceville 7.5-Minute Quadrangle [38087F6]).

The Indian Refining Company is located east of SR 1 and about 1.5 miles east-southeast of this locality. West of SR 1 and about 0.75 mile southeast of here are 20 large product storage tanks. In 1908, this refinery went online, operated by the Indian Refining Company. Texaco Refining and Marketing, Inc. operated the refinery for somewhat more than 37 years from about 1947 until late 1985. Oil Producers Association, Inc., a group of independent producers from Springfield, purchased the facility for start-up in July 1989. Castle Energy Corporation has a limited partnership with the Indian Refining Company.

General Petroleum Geology

The search for petroleum calls for a clear understanding of the potential location of an accumulation of oil and gas. The geologist attempts to identify four factors:

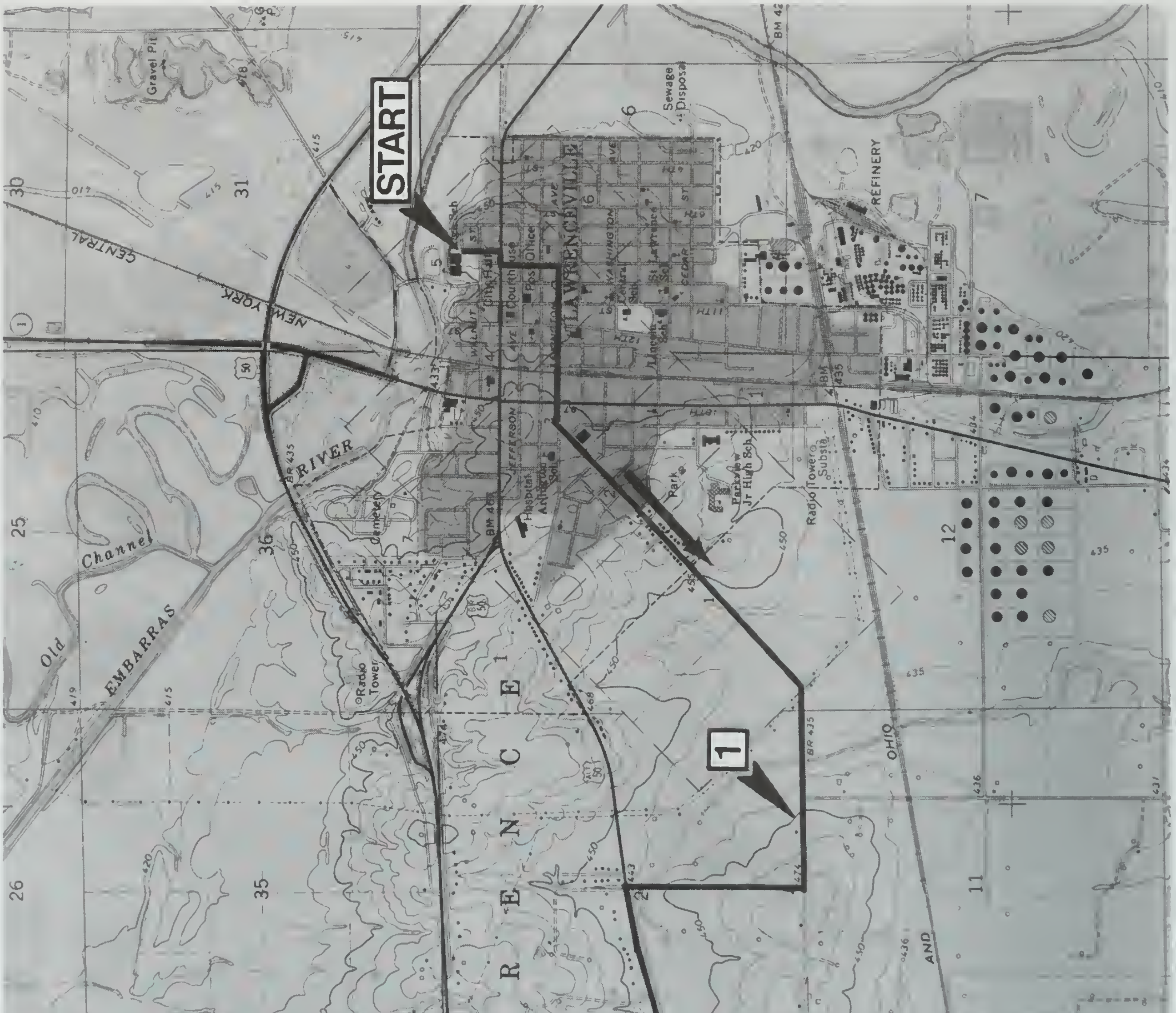
1. The first consideration is locating an original source for the oil and gas. Source rocks, rich in organic matter, have been naturally heated to a point at which the organic material began to be converted to hydrocarbons and expelled from the source. The hydrocarbons then migrated toward a layer of reservoir rock.

2. A reservoir, the second factor, can be thought of as a natural underground container of oil, gas, and water. It must have enough porosity (the amount of voids, pores and other openings in the rock) to store the oil and gas, and enough permeability (the amount of interconnected porosity) to deliver the oil and gas into a well bore drilled through the rock.

3. The nature of the reservoir's *seal* is the third factor to identify. A seal is another layer of rock, usually overlying the reservoir, that has poor porosity and/or permeability. It effectively seals the reservoir and generally prohibits the vertical migration of oil and gas from the reservoir rock.

4. The fourth factor to identify is the trapping mechanism. A trap is the geometric arrangement of reservoir rocks and seals that halts the migration of petroleum. It can be thought of as the final resting place for an accumulation of oil and gas. The trap must be large enough and/or thick enough to make it economic to drill and develop a possible accumulation of oil and gas.

Generally, traps are structural or stratigraphic. Structural traps are the most common and generally the easiest to find. They typically form when layers of rock are folded (bent) by Earth's natural forces into geometric shapes called anticlines (fig. 9). An anticline is a fold that is convex upward and can be thought of as an "underground hill." Stratigraphic traps typically form when the physical properties of a reservoir rock change along its length or lateral extent. An example of a stratigraphic trap is a porous, permeable sandstone bed that laterally changes into a shale bed. The shale, with its poor permeability, traps the oil and gas in the sandstone.


START
1
2
LAWRENCEVILLE
REFINERY
Sewage Disposal
Gravel Pit
NEW YORK CENTRAL
EMBARRAS RIVER
Old Channel
L A W R E N C E
Radio Tower
Cemetery
Hospital
City Hall
Post Office
Park
Parkview Jr High Sch
Drive-in Theater
Cem
OHIO AND BALTIMORE
Bridgeport
0 ½ 1 mi
0 ½ 1 1½ km

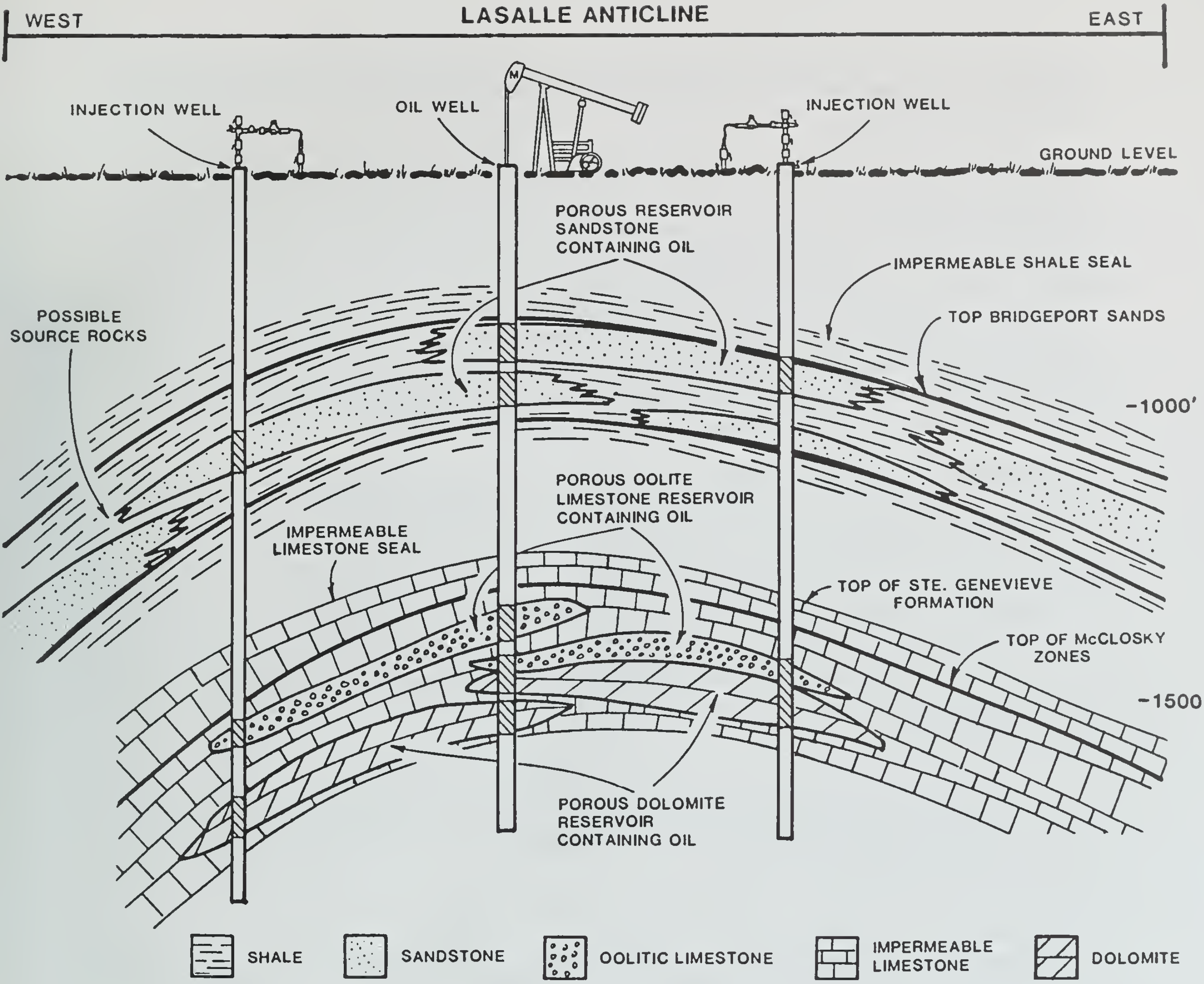


Figure 9 Diagrammatic sketch of Lawrence oil field.

Petroleum Geology of Lawrence Oil and Gas Field

The source(s) for oil and gas in the Lawrence Field are not totally understood. It is thought that these hydrocarbons originated from the organic-rich shales and limestones interbedded with the reservoir rocks. Figure 9 shows the four factors that control the accumulation of oil in the Lawrence Field. Several reservoirs have been proven in the field area, and the stratigraphic section (fig. 2) highlights these productive intervals, also called "pay zones". These reservoirs, such as the Bridgeport sands and the McClosky dolomites and oolites (fig. 9), have good porosities and permeabilities. This allows oil to be stored in and produced from these zones. The seals are tight (low permeability) beds that overly the reservoirs. As shown, overlying shales seal the Bridgeport sands, and tight limestones seal the McClosky zones. Finally, the Lawrence Field is a structural trap. Layered rocks such as the Bridgeport sands and the Ste. Genevieve Formation have been folded into an elongated, dome-shaped fold along the LaSalle Anticlinal Belt. This fold is an effective trapping mechanism and is steeper on the west flank than on the east.

Most geologic knowledge of the Lawrence Field is based on subsurface information because the source rocks, reservoir rocks, and seals are not exposed at the surface near the field area. The lack of outcrops (surface exposures) in Lawrence County makes surface structural mapping impossible; therefore, structural interpretation is based on subsurface data. Drillers' descriptions

from early wells, electric logs from more recent wells, core descriptions from specific intervals, and detailed production and well test information are the type of subsurface data used to characterize the geologic setting of this field.

Currently, the field is undergoing secondary development and in the early stages of tertiary development. ("Secondary" simply means the second attempt to produce from a particular area; "tertiary" refers to a third attempt in the same area.) These phases of development are expensive to implement and require detailed planning to execute, so their success depends upon an adequate geologic understanding of the field. Detailed studies of individual reservoirs begin with their original environments of deposition. For example, the Pennsylvanian-aged Bridgeport sands were deposited some 300 million years ago by streams that were flowing toward the west-southwest and draining stable highlands to the north and east. These sands were deposited as point bars, overbank deposits, and channel sands. Knowledge of the type and orientation of these sand bodies helps in predicting their areal extent and in planning drilling operations.

The Mississippian-aged Ste. Genevieve Formation was deposited some 340 million years ago in a shallow marine environment fairly near the shoreline of an ancient sea that covered most of the present North American Continent. The oolitic beds in the Ste. Genevieve, a series of offshore bars deposited in a high energy environment, are oriented northeast to southwest. The roundness, high degree of sorting, and extremely good permeabilities of the oolites are primarily due to wave action and long shore currents active in this ancient sea during deposition. The dolomitic beds were probably deposited as nearshore lime muds that have been recrystallized and replaced by dolomite, thus allowing for the formation of excellent porosities and enhancing their reservoir characteristics. Again, these geologic interpretations are helpful for effectively planning development operations.

Much development planning is based on geologic knowledge, but reservoir dynamics, historic production performance, and similar data are utilized by petroleum engineers to effectively develop reserves in this field. Joint efforts by geologists and engineers make production operations effective and profitable for oil companies.

Brief History of the Lawrence Oil and Gas Field

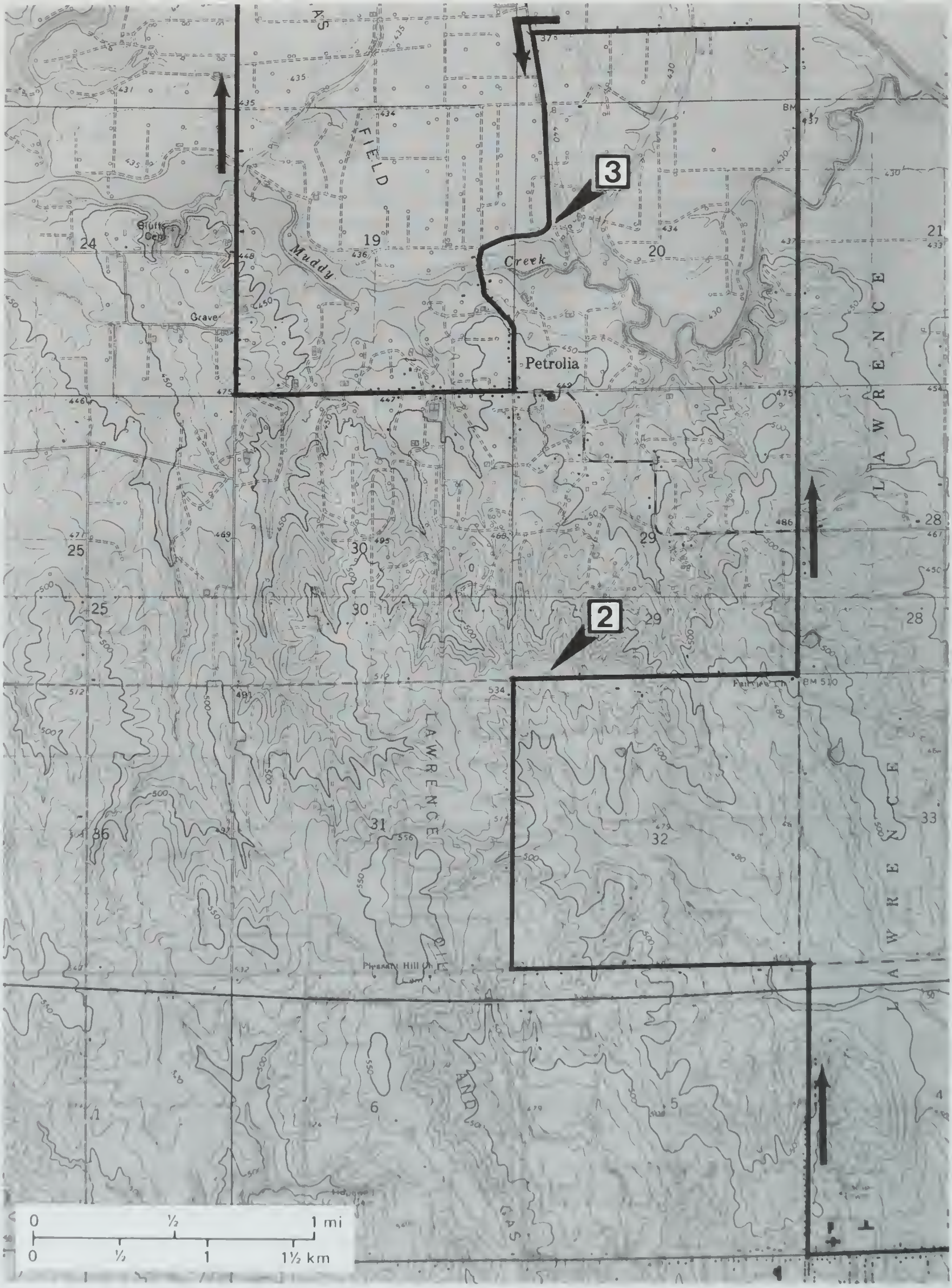
The field was discovered during 1906, and although early production records are sketchy, about 390 million barrels of oil have been produced from 14 major pay zones (fig. 2). During 1909, R.S. Blatchley and assistants determined surface elevations for more than 1,500 wells in Lawrence County. More than 7,300 wells have been drilled in Lawrence County and some 40,000 acres are underlain by proven production.

The deepest production in the field is from the Devonian-aged carbonates (limestones and dolomites) at approximately 3,000 feet. These rocks were deposited about 380 million years ago in a shallow epicontinental sea. The deepest well drilled in the field is the Arco no. 77 J. B. Lewis, which was drilled to a total depth of 9,261 feet in Cambrian-aged sandstones approximately 550 million years old.

The primary development of Lawrence Field took place during the early part of this century. When natural reservoir energy began to be depleted, attempts were made to increase the energy by gas, air, and water injection as early as the 1930s. It became evident that the most efficient method to increase reservoir energy and total production was by waterflooding, which is accomplished by injecting water back into the reservoir at higher pressures. This secondary recovery method is still widely used in the field today; the sketch in figure 9 diagrammatically shows two injection wells and one producing well. As the higher pressure water is injected, it increases the reservoir pressure and as the water slowly moves toward the producing well, it "sweeps" additional oil from the pore spaces in the rock.

There are also active tertiary recovery projects in the Lawrence Field. The first of these was initiated during 1982 and involves the Maraflood™ Process (patented by the Marathon Oil Company). In this process, micellar solutions are injected into the reservoir to release oil from void spaces and grain surfaces and move it towards a producing well. A micellar solution can be thought of as a strong detergent that can dissolve either oil or water, thus reducing the bound fluids in the reservoir and allowing additional recovery of oil from the rock. This process is effective in reservoirs that have already been waterflooded. For example, a typical primary recovery for Bridgeport sands is 250 to 300 barrels of oil per acre foot (about 30% of the original oil in place). A secondary waterflood recovery is an additional 250 to 300 barrels of oil per acre foot (another 30% of the original oil in place). Finally, although not proven, the tertiary Maraflood Process should recover an additional 20% to 40% of the remaining oil in the reservoir. Currently, there are three such projects in the field. The results of these chemical floods will determine how extensively this process can be utilized in future operations.

0.0	2.1+	Leave Stop 1 and CONTINUE AHEAD (west).
0.2	2.3+	TURN RIGHT (north) at the T-intersection (1000N, 1050E).
0.5+	2.85	STOP: (1-way) at the T-intersection with SR 250 (1050N,1050E). TURN LEFT (west).
1.8+	4.65+	CAUTION: enter town of Bridgeport.
0.65+	5.3+	To the right is the Northeast District Production Office of Marathon Oil Company. CONTINUE AHEAD (west).
0.1+	5.45	STOP: (4-way) at crossroad (1000N, 800E). TURN RIGHT (north).
0.9+	6.35+	STOP: (2-way) at crossroad of US 50 (1090N, 800E). CAUTION: fast traffic. CONTINUE AHEAD (north) across US 50.
0.05+	6.45+	CAUTION: T-road intersection (1100N, 800E). TURN LEFT (west) for just over 1 mile.
0.2	6.65+	Cross pipeline. Just beyond to the west and to the right is the J. E. Johnson Lease, Facility 13, Marathon Oil Company, Section 32, T4N, R12W. Notice the many tanks in the background.
0.85	7.5+	TURN RIGHT (north) at the T-intersection (1100N, 700E) onto the gravel road.
1.0+	8.5+	STOP: 1-way at crossroad (1200N, 700E). To the left (west) is the tall "Petrolia" water tower. On the northeast side of the intersection is a sign that reads, "Lewis Treating Plant Section 29-4N-12W, Marathon Oil Company." TURN RIGHT (east).
0.1+	8.6+	PARK along the shoulder as far off the road as you can safely. CAUTION: you are parked in a shallow sag in the road and may not be clearly visible to approaching traffic. BE ALERT!



3
2
Muddy
Creek
FIELD
Petrolia
LAWRENCE
Bluff Cem
Grave
Pleasant Hill Ch
Fairview Ch
BM 510
19
20
21
24
25
28
29
30
31
32
33
36
5
6
0
½
1 mi
0
½
1
1½ km

STOP 2 Lewis Water Treatment Plant (near SE corner, SW SW SW SW. Section 29, T4N, R12W, 2nd P.M., Lawrence County; Sumner 7.5-Minute Quadrangle [38087F7]).

Most of the large-scale oil production from the Lawrence oil and gas field is from the La Salle Anticlinal structure that trends toward the northwest. This structure flattens out a little more than 1 mile to the east. As our itinerary takes us north of the crest of the structure and crosses it diagonally, we are going downdip on the structure as we proceed northward.

Lewis Water Treatment Facility

This stop is located very near the top of the La Salle Anticline and in the heart of production from the northern portion of the Lawrence Field. An injection well lies between the road and the water facility.

The diagram in figure 10 illustrates the steps taken to treat water here. Produced water from about 60% of Marathon-operated waterflood properties in the field is pumped into the large 10,000 barrel surge tank. This commingled water is sent to a Wemco flotation cell where chemicals are added to remove traces of oil. (At Stop 4, we will see how most of the produced oil is separated from the water). A blanket of nitrogen covers the surface of the water in the unit to keep oxygen out of the flotation cell and help reduce the corrosion in the entire treating system. The tall, slender white tank stores the liquid nitrogen used for this procedure. Only 6 to 8 barrels of oil per day are removed from all produced water handled by the Lewis Facility.

From the flotation cell, the water is pumped through a filter system to remove suspended solids. The four large tanks in the center of the facility are upflow sand filters. The water is pumped up through a series of gravel, sand, and fine sand layers in these filters, thus removing the suspended solids. The water is then sent to the 4,000 barrel "clear well" tank where an appropriate amount of fresh water (also called make-up water) is added to maintain the proper volume. This fresh water is produced from the Embarras Valley aquifer tapped by a series of wells northeast of Stop 4.

Corrosion and scaling are prevented in the distribution system by adding chemicals before the water is sent back to the waterflood project areas by 13 powerful pumps located in the long brown building. Altogether, it takes 1,000 to 1,500 horsepower to maintain a pressure of 700 pounds per square inch in the discharge lines.

The Lewis Plant treats between 90,000 and 100,000 barrels of water per day, and approximately 5,000 barrels of this total is fresh water. Therefore, the plant discharges approximately 2,800 gallons of water per minute to the waterflood projects. This water is then reinjected as part of the waterflood operations, and a portion is again produced along with the oil on the leases. At this point, the treatment process begins again.

0.0	8.6+	Leave Stop 2 and CONTINUE AHEAD (east).
0.35	8.95+	Pipeline crossing.
0.5+	9.5+	STOP: 1-way (1200N, 800E) at T-intersection. Fairview United Methodist Church stands on the southwest corner. CAUTION: limited visibility to left. TURN LEFT (north).
0.5+	10.0+	CAUTION: crossroad at (1250N,800E). CONTINUE AHEAD (north) on a rough oil and chip road.

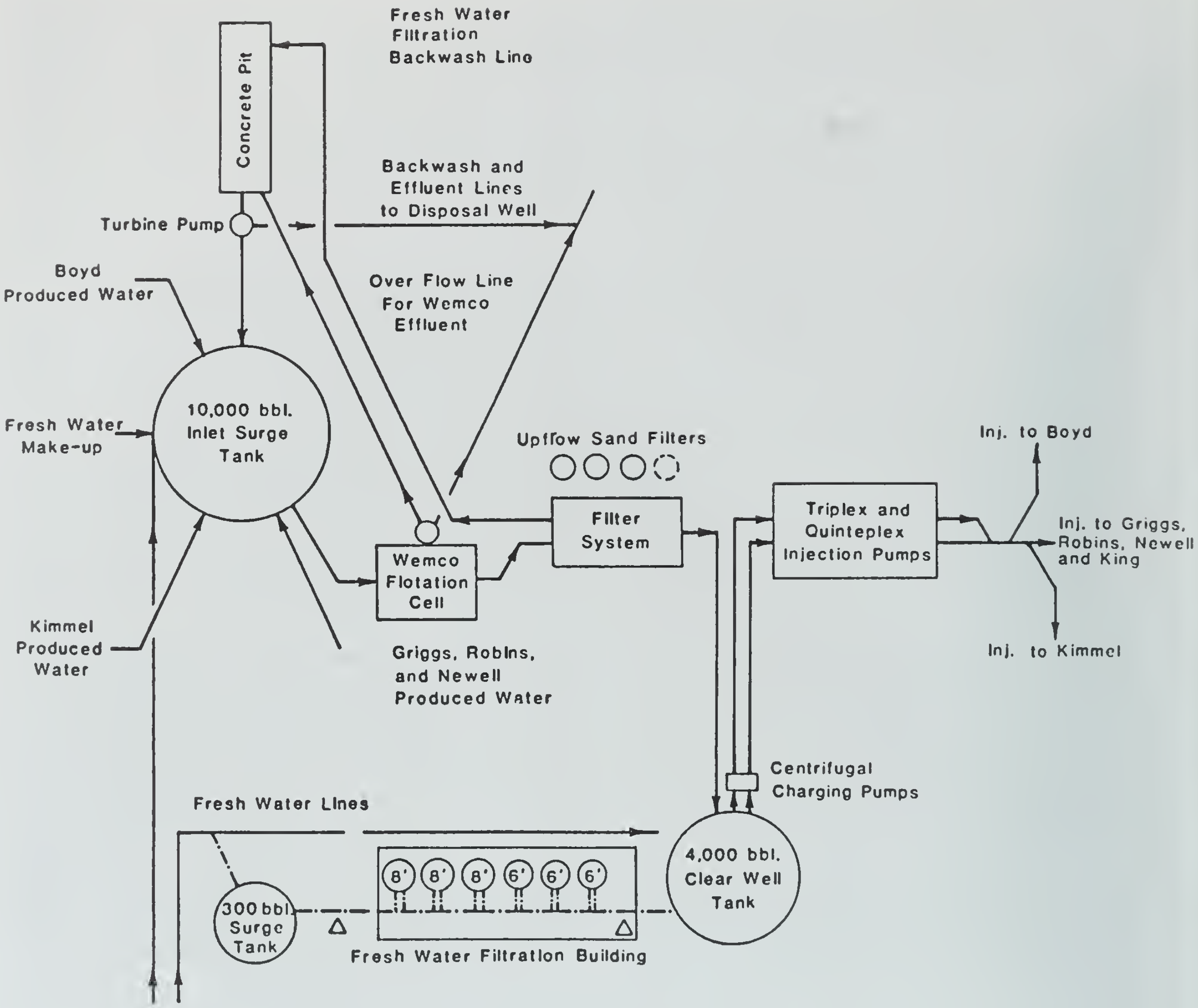


Figure 10 Water treatment stages.

1.15+	11.2+	Cross Muddy Creek.
0.3+	11.5+	CAUTION: loose gravel ahead.
0.25+	11.8+	CURVE LEFT (west) at 1420N, 800E.
0.9+	12.75+	CAUTION: T-intersection (1420N, 710E). STOP—just to be safe, even though there is no stop sign. Visibility is very limited when crops are high. We are stopped above Marathon Oil Company pipeline. VIEW to right (northwest) at about 1:30 o'clock of the tank battery at Marathon's Ridgely–Westall Facilities 4 and 5. TURN LEFT (south).
0.65	13.4+	PARK along the shoulder as far off the road as you can safely. PLEASE stay out of fields and away from pumpjacks and other equipment.

STOP 3 Pumpjacks in the Lawrence Oil and Gas Field: the area beyond the treeline, a little more than 1/10 mile west, is the northern part of the Enhanced Recovery Study (ERSA), one of the sites studied as part of the ISGS Improved Oil Recovery Program. Three different sizes of pumpjacks stand to the left, quite close together. They are recovering oil from different pay zones. (W side of road, NE SW SW NW, Section 20, T4N, R12W, 2nd P.M., Lawrence County; Chauncey 7.5-Minute Quadrangle [38087G7]

Improved and Enhanced Oil Recovery through Reservoir Characterization
The ISGS is completing a major, 4-year research program aimed at providing information to maximize hydrocarbon recovery. Estimates are that 1.5 billion barrels of unrecovered mobile oil (UMO) remain in Illinois reservoirs after normal production. Using advanced methods, scientists are evaluating remaining reserves in Illinois oil fields. This project provides information on hydrocarbon resources, reservoir characterization, and methods to improve mobile hydrocarbon extraction. One of the Illinois fields under study is Lawrence Field. A report on this significant study is soon to be published in the ISGS Illinois Petroleum series (Grube 1994).

Lawrence Field Project The Mississippian Cypress Formation (fig. 2) is the most prolific producing horizon in the Illinois Basin. Nearly 1 billion barrels of oil have been produced from the sandstone reservoirs in the Cypress. Primary and secondary (waterflooding) development have not necessarily drained all of the movable oil from these reservoirs. Economically recoverable, unswept mobile oil (UMO) most likely remains in many Cypress reservoirs. A comprehensive geologic investigation integrated with engineering analysis of all production-related reservoir characteristics is necessary to evaluate and produce the remaining recoverable reserves. Drilling, completion, and stimulation methods; well spacing; reservoir pressure maintenance; and waterflood design are all highly dependent on characteristics of individual reservoirs.

Lawrence Field occupies approximately 62.5 square miles in Lawrence County, Illinois (fig. 11), and has produced more than 400 million barrels of oil from 23 separate horizons since its discovery in 1906. The Cypress (Mississippian) and the Bridgeport (Pennsylvanian) sandstones are the most productive horizons in the field. It is estimated that the Cypress sandstones have yielded about 260 million barrels of oil from more than 4,000 wells.

This study was conducted to evaluate the geologic characteristics of the Cypress reservoirs (locally called the Kirkwood) in a central portion of Lawrence Field for the purpose of determining the amount, location, and reason for the presence of bypassed oil in the pilot study area and to investigate improved oil recovery techniques. The pilot study area in Sections 19 and 30, T4N, R12W, was chosen on the basis of availability of core analyses and whole core, in combination with the presence of a Cypress reservoir section that is typical of the field.

Many electric logs, cores, and core analyses accompanied the initiation of the waterflood phase in the field in the mid-1950s. A detailed reservoir analysis program was conducted in the 1980s. The combined result was a large amount of petrophysical data previously unavailable for the area. These data were used both to map and interpret depositional facies and reservoir geometries. The data were also used in three-dimensional, geological, computer modeling to show the distribution of lithology, porosity, and permeability of reservoir rocks. The information was then used to identify potential recoverable reserves and recovery techniques.

General Geology
Structure Lawrence Field is located on the southern end of the south-southeast-trending La Salle Anticline. Two closed structures separated by a saddle define the field (fig. 11). This study focuses on a portion of Sections 19 and 30 positioned along the crest of the northern structure. Approximately 350 feet of closure is indicated on the Barlow structure map for the northern anticline. The top of the reservoir in the study area lies at a depth of 1,350 feet, with a ground

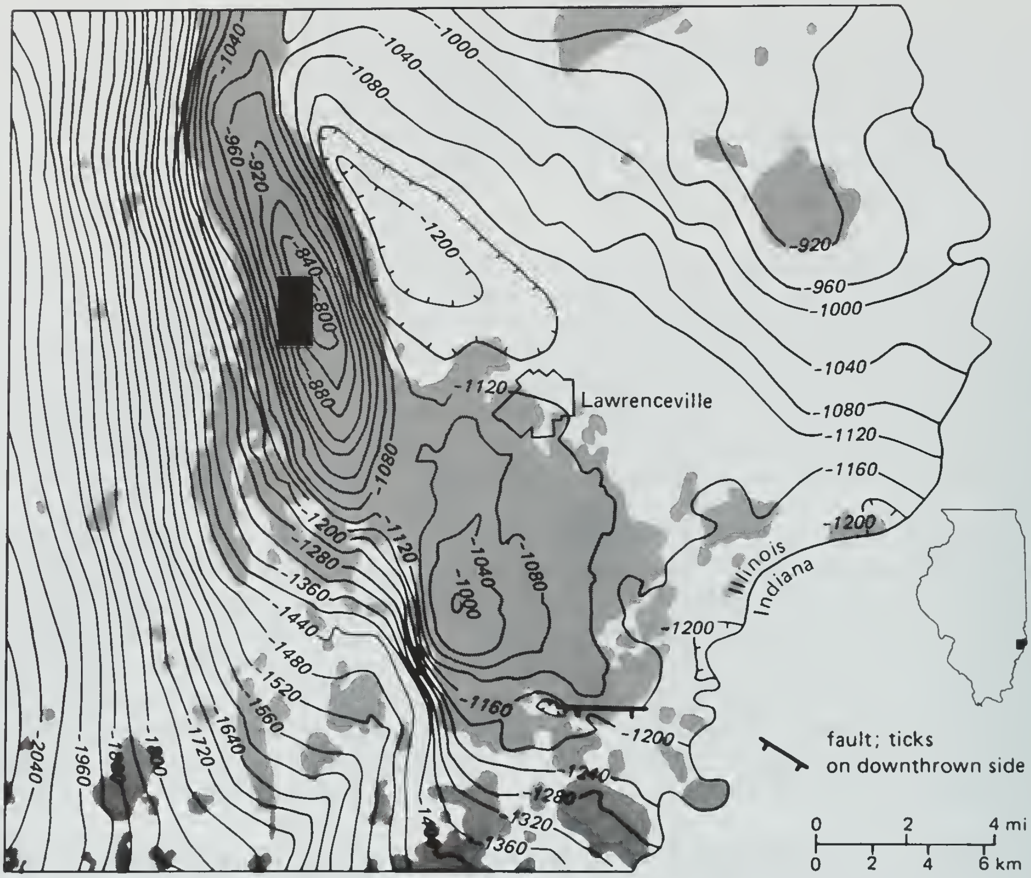


Figure 11 Regional structure map on the top of the Barlow Limestone shows Lawrence Field and the location of the study area (black rectangle).

elevation of about 500 feet. Cypress reservoirs along the crest of the anticline are generally full of oil. Although oil accumulation is largely controlled by structure, stratigraphy is a significant factor that affects the ultimate amount of oil recovered.

Stratigraphy In the Lawrence Field area, the Cypress Formation consists predominantly of sandstone and shale. Incorporated within the sandstones are a few distinct beds, less than 1 foot thick, of sandy limestone to very calcareous sandstone. Where present, the reservoir sandstones are generally found about 40 feet below the base of the Beech Creek (Barlow) Limestone (fig.12). The intervening interval consists of shale, siltstone, and shaley or calcareous sandstone. In some cases, a red and green variegated to mottled mudstone immediately overlies the reservoir sandstone.

Core studies show that the sandstones are fine to very fine grained. Beds are generally thinner than 6 inches, planar, and small-scale, wavy and ripple laminated. Wispy to continuous clay laminations one to several grains thick are common throughout the sandstones. Some of these laminations contain fossil plant material on bedding surfaces. The clay laminations combine to form intercalated sandstone and shale zones or shale beds several inches to approximately 10 feet thick. Marine trace fossils, while rare, are present in both the sandstones and shales.

The electric log response, particularly the spontaneous potential (SP) character, core observations and permeability values, were used to divide the sandstones that make up the reservoir interval into five zones, A–E, in ascending order (fig. 12). Not all zones are necessarily present in

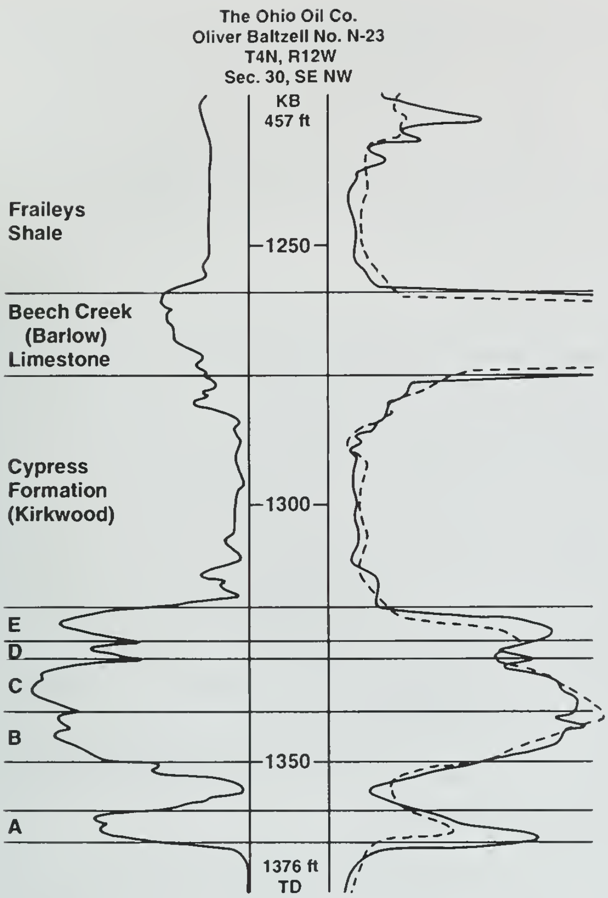


Figure 12 Typical log of the Cypress Formation in the study area. The Cypress sandstones can be divided into 5 distinct zones, A through E.

any particular area. The A zone is commonly tight and separated from the others by shale; it does not appear to contribute significantly to production. Zones B–E, the primary reservoir, appear cyclical, particularly on logs; they are separated from each other by thin, low permeability, shaley sandstones, shales or calcareous beds. Individual zones are generally less than 10 feet thick; however, the combined sandstones are variable—as much as 40 feet thick in some parts of the field and completely absent in others.

Isopach maps were constructed for the five sandstones. Zones B–E show very similar geometric characteristics. Elongate, sheet-like sandstones that form with, thick, northeast-southwest-trending ridges are common to all four zones.

Depositional Environments The rare marine trace fossils and thin calcareous beds observed in the Cypress reservoir cores are evidence for deposition in a marine setting. Supporting this interpretation is the widespread, elongated, parallel-ridged, sheet-like geometry of these sandstones. Thin planar bedding combined with wavy and ripple laminations indicates deposition by moderate currents; wispy to continuous clay laminations indicate slack periods. Scattered carbonaceous material was most likely derived from the woody plant material from a nearby delta. Thin shale and shaley sandstone beds, and possibly the calcareous beds, may have been deposited during periods when coarse clastic (sand) input from the delta was low; whereas the carbonate (limestone) may have formed during periods of no clastic input. The variegated, mottled, laminated to structureless mudstones capping the sandstones appear to be marsh/mudflat sediments that were subjected to subaerial exposure—features suggesting that the underlying sandstones were deposited in a shallow marine environment near the shore line.

Development and Production Implications The most significant production and development implications presented by the reservoir characteristics revealed in this study relate to the effectiveness of the production and injection well locations and the flow paths of the secondary sweep (waterflooding) within the four stacked and impermeably bounded zones. There appear to be regions where reservoir rock changes facies to nonreservoir rock. Because of spacing, location, and arrangement of production and injection wells, flow paths thus bypassed portions of each reservoir zone. This may take place in any zone.

ISGS GEOLOGICAL SAMPLES LIBRARY

The Illinois State Geological Survey (ISGS) manages one of the largest collections of geological samples in the United States. The Geological Samples Library is the repository for drilling samples in Illinois, as mandated by the state. The Natural Resources Studies Annex on the campus

of the University of Illinois at Champaign–Urbana houses the Geological Samples Library (GSL). As of July 1, 1993, the collections contained 67,770 sets of drill cuttings from oil and water wells, representing more than 743 million total feet of drilling. The collection also includes 1 million feet of core from 13,801 drill holes.

All items in the GSL collections are listed in a card catalog according to county, geographic location (township and range grid), company, lease name, depth of drill hole, type of sample, and number of boxes. For information about the availability of sample material for a particular location you may contact the GSL staff.

More about the Collections Most drill cuttings on file in the GSL were obtained from oil tests. The Oil and Gas Division of the Illinois Department of Mines and Minerals requests samples on permits issued by their office and administers the compliance program regarding requested samples. Samples are requested for any permit issued for a site that is in an area where no samples have been obtained previously, or at a location more than ½ mile from a previously drilled well with samples on file at the GSL. Samples also are requested if a permit is issued for a well targeted for a deeper formation within the same ½ mile radius. Drill cuttings from 5- or 10-foot intervals are typically saved. Upon receipt at GSL, they are sorted, washed, filed in paper envelopes, and then stored in cardboard boxes with an unique file number. The collection of cuttings presently comprises 1.5 million individual samples in more than 103,730 boxes. Data such as scout tickets and electric logs from the oil and gas wells are available at the GSL in microfiche form. The GSL also maintains a large collection of sample sets from water wells drilled throughout Illinois and holds about 37,265 miscellaneous items from various research projects. The core collection was obtained primarily from coal, oil, stratigraphic and mineral tests, and various shallow engineering borings. Most of the core on file was condensed from its original form, although in the last 8 years, saving the continuous core sets has been emphasized.

Using the Samples Library Room 102E of the Natural Resources Studies Annex contains both the Samples Library Office and the Sample Study Laboratory. The Samples Library provides visitors with ample space for studying samples.

Visitors are required to register with the Samples Library Office to obtain permission to study the collections. The library staff assists visitors in sample retrieval and layout. Samples are not loaned, but selected sampling of the collection is permitted with prior approval of the Technical Services Group Head. A study area equipped with a microscope and an ultraviolet light is available for examination of samples. No fee is charged for studying samples and no appointment is necessary. For more information, contact the Geological Samples Library, Ilinois State Geological Survey, Natural Resources Building, 615 E. Peabody Dr., Champaign IL 61820. Phone (217) 333-3567. Hours are 8:00 a.m. to 5:00 p.m., Monday through Friday.

ISGS GEOLOGICAL RECORDS UNIT

The Geological Records Unit (GRU) is the repository for drilling records in Illinois, as mandated by law. This collection includes oil and gas wells, water wells, engineering borings, and miscellaneous test holes. This database has long been of value to the oil and coal industries as well as to hydrogeolgists, engineers, land-use planners, academic institutions, landowners, the general public, and ISGS staff.

More about the Collection The primary function of GRU is to collect and integrate well data into the existing database and make this information available to staff and public. The Illinois Department of Mines and Minerals (IDMM) provides permit information about new oil and gas wells to the ISGS. Operators are responsible for providing data to the ISGS, as required by IDMM rules. The ISGS also cooperates with the Illinois Department of Public Health, the Illinois

Environmental Protection Agency, and the State Water Survey to add information from public, private, and municipal water wells to the database.

The extensive GRU well data collection contains more than 375,000 records from oil, water, and other miscellaneous wells. This ongoing collection of data contains well records from the early 1900s to the 1990s. Customer services provided by GRU include a telephone information service, visitor access to paper data files, computer searches, and the sale of paper copies of records.

Using the Geological Records Unit The GRU is located in room 227, Natural Resources Building, where there is ample space for visitors to examine records. Visitors are required to sign in at the reception desk to obtain permission to use the facility. A well copy service is provided at a nominal cost by GRU staff. Requests for information can also be taken by phone, mail, or telefax. For more information, contact the Geological Records Unit, Illinois State Geological Survey, Natural Resources Building, 615 E. Peabody Drive, Champaign IL 61820. Phone (217) 333-5109. Telefax (217) 333-2830. Hours are 8:00 a.m. to 5:00 p.m., Monday through Friday. No appointment is necessary.

0.0	13.4+	Leave Stop 3 and CONTINUE AHEAD (south and west).
0.35+	13.75+	CAUTION: cross Muddy Creek on an old, 1-lane iron bridge and enter the community of Petrolia.
0.45+	14.25	STOP: 2-way at crossroad (1300N, 700E). TURN RIGHT (west) on the blacktop.
0.25	14.5	VIEW to left is of Marathon's Boyd Facility on the hilltop.
0.3	14.8	VIEW to the right shows several tanks of Marathon's Willey Facility 8 (Section 19, T4N, R12W).
0.4+	15.2+	CAUTION: T-intersection (1300N, 600E). TURN RIGHT (north). We are going up the west side of the northern part of the ERSA study area.
0.75	15.95+	Cross Muddy Creek.
0.75	16.7+	PARK along the roadside as far off the pavement as you can safely. BE ALERT for fast traffic. You MUST HAVE PERMISSION to enter these facilities. DO NOT CLIMB on anything here.

STOP 4 Applegate LACT Unit, Facility 2, Marathon Oil Company: we'll discuss the waterflood operation and well spacing at this site (near SE corner, NE Section 13, T4N, R13W, 2nd P.M., Lawrence County; Chauncey 7.5-Minute Quadrangle [38087G7]).

Applegate Production Facility 2

This stop, also located near the top of the producing structure, is a typical production facility. The series of tanks are commonly called a tank battery; and the tanks on the south side are receivers, whereas those on the north are stock tanks. The produced fluid (oil and water) from an individual lease enters a separate receiver. The production from each lease is kept separate, which explains the number of tanks at this facility.

P E T T Y
Pleasant Hill Ch
OLD INDIAN TREATY BOUNDARY
Creek
The Muddy
AND GAS FIELD
4
Bluffs Cem
Grave
P E T T Y
RED HILL
Red Hill Chapel
5
LUNCH
0 ½ 1 mi
0 ½ 1 1½ km

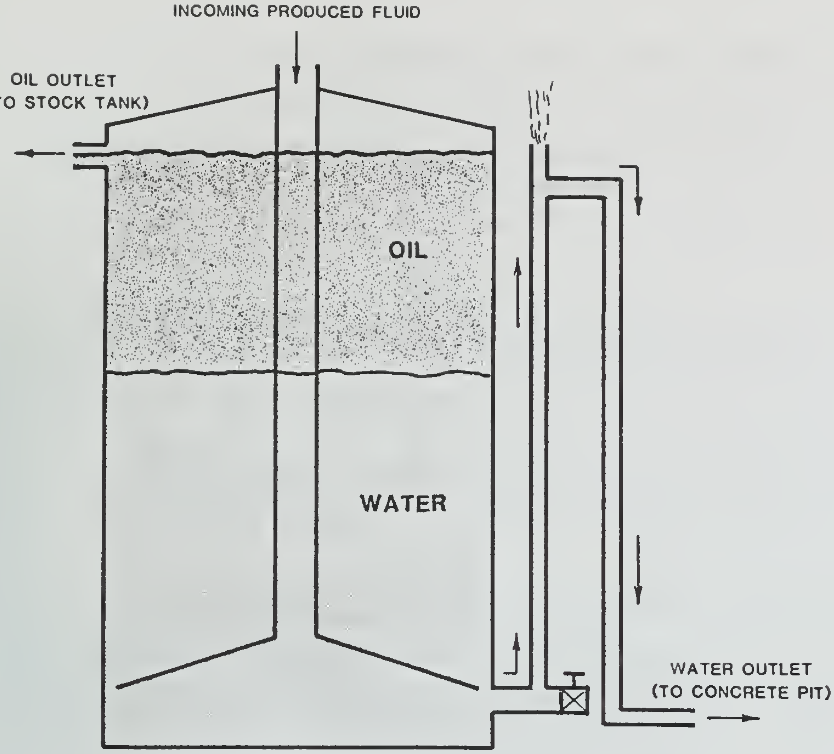


Figure 13 Typical receiver.

Fgure 13 shows how produced fluids enter the top of the receivers. The less dense oil floats to the top of the receiver and flows into the adjoining stock tank,while the water flows out the bottom of the receiver through a siphon into a concrete pit before being pumped back to the Lewis Plant.

When a stock tank fills with oil, it triggers an electronic signal to the LACT (lease automatic custody transfer) unit. The LACT unit opens the appropriate valves and allows the transfer of oil from the producing company to the pipeline purchasing company. The LACT unit measures the amount of oil that is being sold with a series of meters and monitors the impurities in the oil. When the tank reaches its preset low level, the LACT unit shuts the valves and records the transfer. The LACT unit also has built-in features that cause automatic shut-down if a problem is encountered; for example, if a leak develops in a line, or the impurity level of the oil becomes too high. These LACT units are carefully checked on a predetermined scheduled.

The Illinois Department of Mines and Minerals has required that existing clay-lined earthen pits be abandoned. The fresh top soil north of the tank battery is the reclaimed site of an abandoned pit, and the recent wet weather has delayed the final grading and seeding of this area. The new concrete pit now serves to hold produced water prior to treatment and reinjection. It is surrounded by a fence to protect personnel working near the facility as well as wildlife in the area.

Across the road, you can view the typical surface equipment and pattern utilized in a waterflood operation. The relative location of injection and producing wells is called a five-spot pattern, which means that one producer is affected by four injectors, and at the same time, one injector is serving four producers. This pattern allows for maximum recovery from the characteristic reservoirs in the Lawrence Field.

0.0	16.7+	Leave Stop 4 and CONTINUE AHEAD (north).
0.5+	17.2	TURN LEFT (west) at crossroad (1500N, 600E). CAUTION: loose gravel.

0.75+	17.95+	Cross concrete bridge over The Slough. CONTINUE AHEAD (west).
0.15+	18.15	CAUTION: T-road intersection (1500N, 500E) with NO STOP. About 50 feet before the intersection, you will cross the western Indian Treaty Boundary. TURN RIGHT (north) and prepare to turn left.
0.05+	18.2+	TURN LEFT (west).
0.85+	19.1	CAUTION: the sides of a concrete culvert are very low and difficult to see. DON'T DRIVE OFF THE EDGE into the ditch.
0.1+	19.2+	CAUTION: crossroad (1500N, 400E). TURN LEFT (south).
0.35	19.55+	You are starting to descend into the wide valley of Muddy Creek.
0.2+	19.8	CAUTION: loose gravel.
0.7+	20.5+	Concrete bridge crosses Muddy Creek.
0.7+	21.25+	T-intersection from left (1300N, 400E). CONTINUE AHEAD (south) on an old single lane, concrete slab—some of the first concrete road laid down in the area for use as a farm-to-market road. CAUTION: it is rough!
1.0	22.25+	STOP: 1-way at T-intersection (1200N, 400E). TURN RIGHT (west) and prepare to turn left.
0.05	22.3+	TURN LEFT (south) up a hill onto a narrow road. This is the north entrance to Red Hills State Park.
0.25+	22.55+	CAUTION: just below the crest of the hill, watch out for a bad bump!
0.05	22.6+	The elevation of this hill is slightly more than 630 feet msl. The park brochure notes that this the highest point between Cincinnati, Ohio, and St. Louis, Missouri.
0.6+	23.2+	CAUTION: T-road intersection with no stop sign. Visibility is very limited to the left. The historical marker to the right (northwest corner) reads as follows:

Vincennes Tract The western boundary of the Vincennes Tract passed through this point. The line extended south-southwest thirty-nine miles from present-day Crawford through Lawrence, Wabash, and Edwards Counties in Illinois. The Vincennes Tract was seventy-two miles wide. About six-sevenths of it lay in Indiana. The Illinois portion was the first parcel of land in the Illinois country ceded by Indians. The land was ceded in the treaty of Greenville, August 3, 1795, and confirmed in a treaty at Fort Wayne, June 7,1803. Acting for the United States, William Henry Harrison, Governor of Indiana Territory, negotiated the 1803 treaty with the Delaware, Shawnee, Potawatomi, Miami, Eel River, Wea, Kickapoo, Piankashaw, and Kaskaskia Tribes. Illinois was then a part of Indiana Territory. (Lawrence County Historical Society and the Illinois State Historical Society, 1973).

According to the Sumner 7.5-Minute Quadrangle Map, this marker is not placed accurately. It should be located about 600 feet west of its present position.

CAUTION: TURN RIGHT (west) on the Cahokia Trace.

0.1+	23.3+	The white-painted culvert here is very close to the western boundary of the Vincennes Tract. Perhaps the marker should be placed here.
0.05+	23.4+	BEAR RIGHT (north) on the driveway along the east side of the shelter house.
0.05+	23.5	PARK parallel to roadway in parking areas around the pavilion.

STOP 5 LUNCH at the shelter: we'll talk about land surveys in the Lawrenceville area (shelter: near SE corner, NW SE NW SE, Section 34, T4N, R13W, 2nd P.M., Lawrence County; Sumner 7.5-Minute Quadrangle [38087F7]) .

Here we have the opportunity to examine the system of land surveys in Illinois. The 15- and 7.5-minute quadrangles show that section lines do not form an even grid over the whole field trip area. Note that some sections are considerably larger than others.

In 1804, initial surveying from the 2nd P.M. (fig. 14) continued westward from Vincennes, Indiana; this survey became the basis for surveying about 10% of what is now eastern Illinois. Because the western boundary of this tract had not been established with certainty, it was decided in 1805 to designate the 3rd P.M. as beginning at the mouth of the Ohio River and extending northward to facilitate surveying new land cessions. By late 1805, a base line had been run due east to the Wabash River and due west to the Mississippi River from the 3rd P.M. During March 1806, surveying commenced northward on both sides of the 3rd P.M. Some time after the selection of an initial point from which to establish a base line, and from which the surveys were to be laid out, the base line apparently was arbitrarily moved northward 36 miles, where it roughly coincides with the base line of the 2nd P.M.

The township and range system permits the accurate identification of most parcels of land in Illinois to facilitate the sale and transfer of public and private lands. In the early 1800s, each normal township was divided (to the best of the surveyor's ability) into 36 sections, each of which was 1 mile square and contained 640 acres (see route maps).

Township and range lines in figure 15 do not form a perfect rectangular grid over the state because of the use of different base lines and principal meridians and because minor offsets were necessary to compensate for Earth's curvature. The surveying corrections producing the minor offsets were usually made at regular intervals of about 30 miles. Figure 15 also shows what happened when the survey from the 2nd P.M. met the survey from the 3rd P.M. From Iroquois County south to White County, only narrow partial townships could be made where the two surveys met. These partial townships are all located in R11E, 3rd P.M., and in most places, are less than one section wide.

Closer at hand, recall the road offset north and west from Stop 4. The Indian Treaty Boundary, the western boundary of the Vincennes Tract, has a greater effect on section lines in some places than in others. Check the route maps carefully to see whether you can find some of the small pieces of sections that are somewhat out of kilter. The western tier of sections in T4 and 5N, R11W, are quite narrow. Most are only slightly more than 0.75 mile wide. Can you find any in that tier that are wider than the rest? At least you can use the rectangular land surveys sytem to describe locations in these sections. Things are not quite so easy, however, when you look at the city of Lawrenceville. Notice the numbered rectangles that are oriented southeast-northwest. An engineer from the area told me that boundaries like those and the French land grants along the Wabash made him decide long ago that land surveying in this area was not his thing! Apparently, tracts are handled differently, depending on where you are located. A good student project would

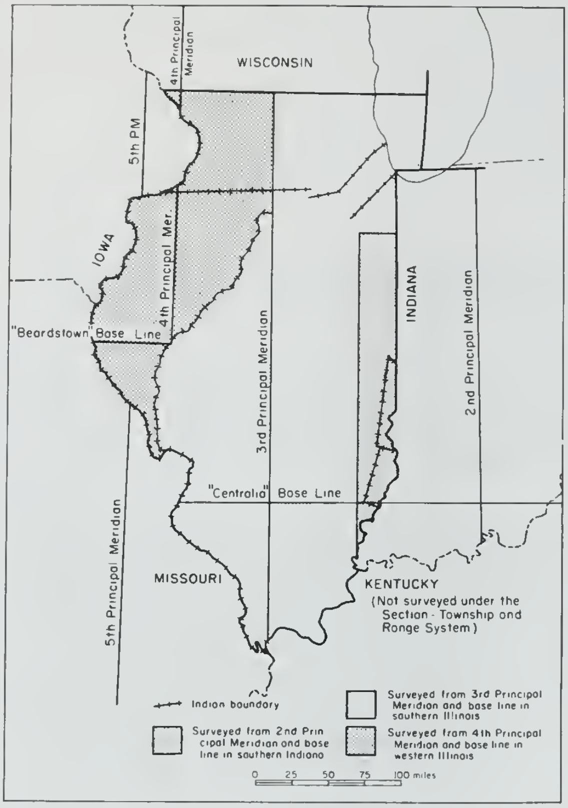


Figure 14 Principal meridians and base lines of Illinois and surrounding states (Cote 1978).

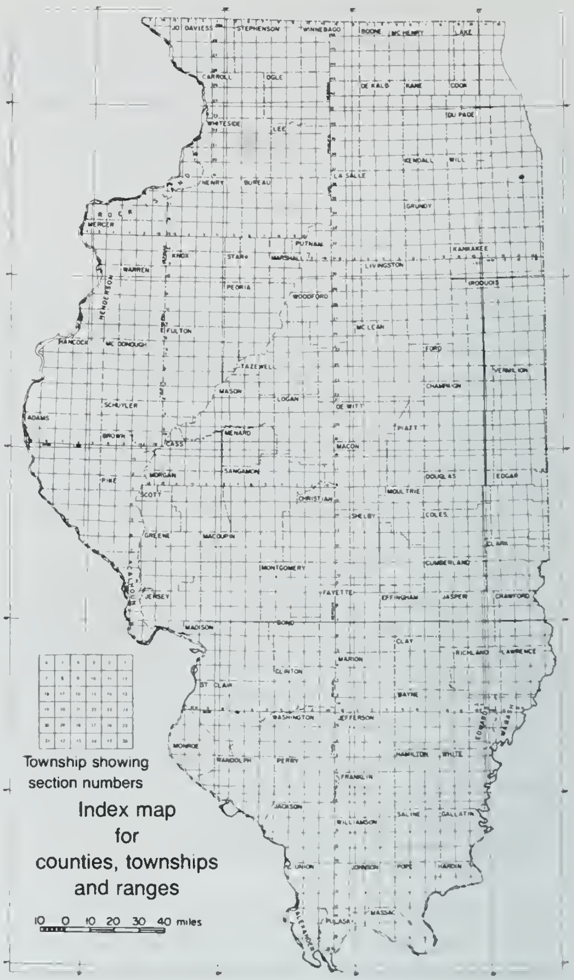


Figure 15 Index map (Cote 1978).

be to find out how locations are legally recorded for these tracts. Check with the surveyor who does this type of work for the city.

Get out your quadrangle maps and have some fun. What other anomalies can you find? If your supply of topographic maps is limited, call us at the Illinois State Geological Survey (333-4747) for a free index to the topographic maps of Illinois. When you decide which ones you want or need, you may also purchase them from us.

0.0	23.5	Leave Stop 5. CONTINUE AHEAD on the driveway.
0.15+	23.65+	CAUTION: intersection with main park road; no stop signs. BEAR LEFT (southeast) on the main park road (Cahokia Trace) to US 50.
0.3+	24.0	T-intersection from left. CONTINUE AHEAD (southeast) on the Cahokia Trace.
0.7+	24.7+	STOP: 2-way at US-50. CAUTION: fast cross traffic. TURN LEFT (east).
2.35+	27.1+	VIEW to the right below the highway shows the remnants of a central power unit for pumping several oil wells. The small corrugated metal building near the

		stream and metal and wood scraps also near the stream are all that remain of this facility.
1.05+	28.15+	CAUTION: Bridgeport Road. CONTINUE AHEAD (east).
2.8+	31.0+	CAUTION: approaching Lawrenceville interchange.
0.15+	31.15+	BEAR LEFT (northeast) at the Lawrenceville exit toward the Lawrenceville–Marshall interchange.
0.1+	31.25+	Cross over Business US 50.
0.3+	31.5+	Prepare to pull over and stop on the shoulder of the road.
0.1+	31.75	PARK on road shoulder off the pavement. CAUTION: fast traffic! *Do not cross the highway!*

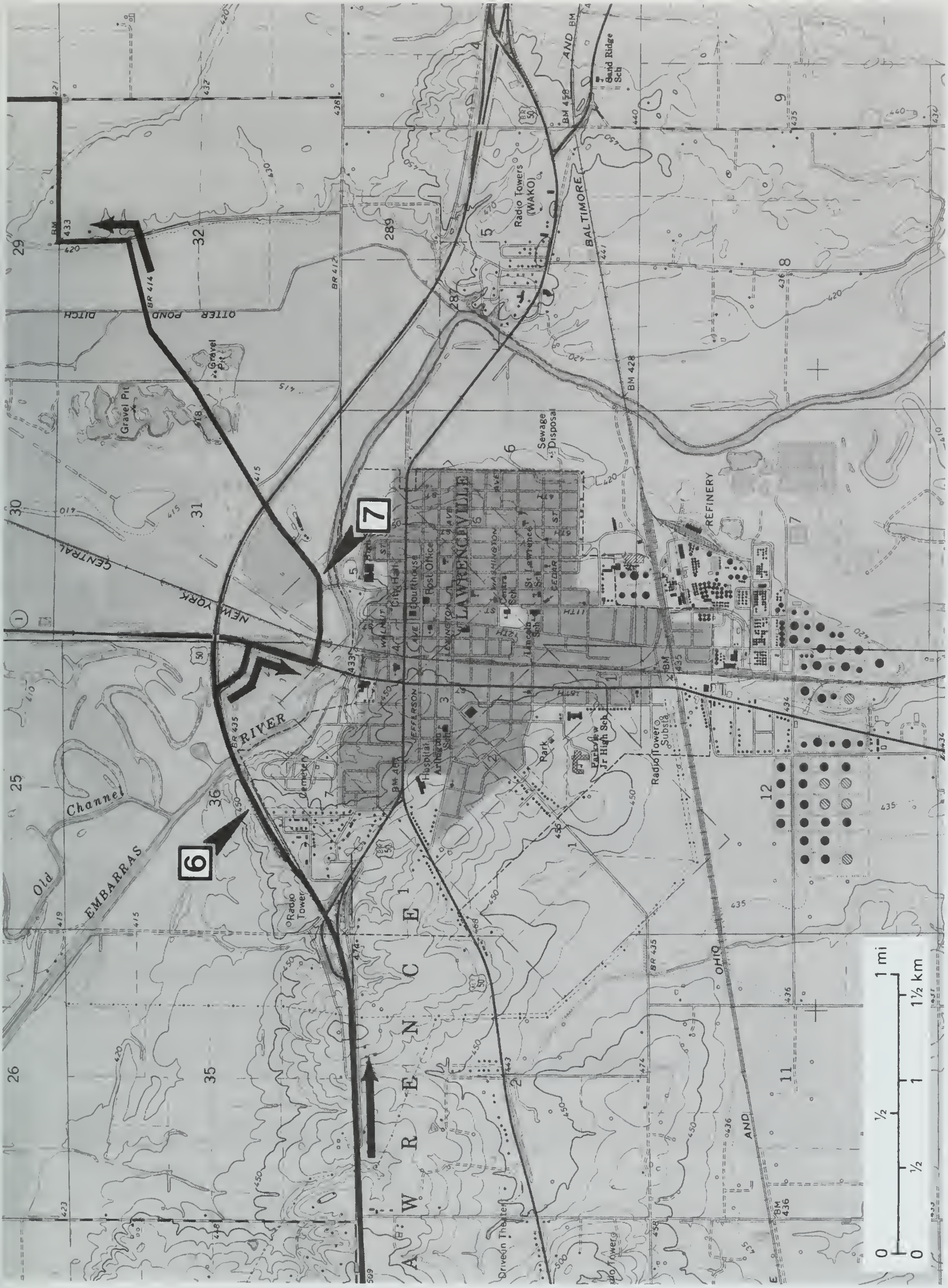
STOP 6 Pennsylvanian bedrock exposure and landslide in a highway cut (SE side of highway US 50 near SE corner, NW SE NE SW, Section 36, T4N, R12W, 2nd P.M., Lawrence County; Lawrenceville 7.5-Minute Quadrangle [38087F6]).

Along the south side of the US 50 roadcut, Wisconsinan windblown silt (loess) overlies Illinoian glacial drift that contains a fairly large amount of water, which leads to an unstable slope. Water percolating down through some 15 feet of this material encounters an underlying Pennsylvanian shale that is relatively impermeable. Because the water cannot flow downward through the shale, it flows laterally along the contact, moving toward the roadcut where it forms a small spring. This also keeps the shale slick. The glacial materials in this instance are quite unstable because of their water content and the slick, underlying shale. As a result, the glacial drift sloughs off readily, letting the slope above it collapse or slump.

At times, it is quite difficult to see the bedrock strata here because of the slumped material from above. You may be able to see a thin coal beneath the shale and some underclay below the coal. None of these bedrock strata are very stable because they are thin and get slick or gummy when wet. If you are lucky, you may be able to collect a small sample of coal from this area. But because of the unstable slope materials here, I would not do very much digging.

0.0	31.75	Leave Stop 6 and CONTINUE AHEAD (east). Please be careful getting back on the highway.
0.15+	31.9	Cross Embarras River.
0.25	32.15	TURN RIGHT (south and then east) at the Lawrenceville–Marshall exit.
0.2+	32.35+	STOP: 1-way at intersection with SR 1. TURN RIGHT (south) on the divided 4-lane highway.
0.1+	32.5	CAUTION: highway narrows to two lanes, not divided. Prepare to turn left.
0.05+	32.55+	CAUTION: TURN LEFT (east) just before the Embarras River bridge.

LAWRENCE
LAWRENCE OIL AND GAS FIELD
Bridgeport
Indian Creek
BALTIMORE AND OHIO
Drive-in Theater
Radio Towers
Radio Tower
Sewage Disposal Plant
Cem
0 ½ 1 mi
0 ½ 1 1½ km


LAWRENCEVILLE
EMBARRAS
RIVER
Old Channel
OTTER POND DITCH
NEW YORK CENTRAL
BALTIMORE AND OHIO
Gravel Pit
Radio Towers (WAKO)
Sand Ridge Sch
Sewage Disposal
REFINERY
Post Office
Courthouse
City Hall
Hospital
Cemetery
Radio Tower
Parkview Jr High Sch
Park
Drive-in Theater
6
7
0 ½ 1 mi
0 ½ 1 1½ km

0.05+	32.65+	CAUTION: rough abandoned PennCentral (PC) rail crossing. CONTINUE AHEAD (east).
0.15+	32.85	CAUTION: Y-intersection (1110N, 1220E). BEAR RIGHT (southeast) and prepare to park.
0.05-	32.85+	PARK along the roadside just before the approach to the 10th Street Bridge. Do NOT block the approach from either direction. CAUTION: watch for traffic coming from both directions.

STOP 7 From the bridge, we'll have a good view of Pennsylvanian strata exposed in the south bank of the Embarras River (north end of the bridge, about 580 feet from the NE line and about 3,180 feet from the SE line, Tract 5 or SW SW SE SW, Section 31, T4N, R11W, 2nd P.M., Lawrence County, Lawrenceville 7.5-Minute Quadrangle [38087F6]).

When the Embarras River is low, the following section can be examined along the south side of the river west of the old iron 10th Street Bridge:

8+ in.	Shale – light to medium gray in lower 6 inches, olive in top 2 inches; well laminated, blocky.
2 ft 6 in.	Limestone – lenticular masses that are up to 3 inches thick and weather into nodules; medium gray with rusty surface. Lenses occur in a medium to dark gray calcareous shale. Both the limestone and shale are quite fossiliferous (brachiopods, horn corals, crinoid stem fragments, gastropods). A rather prominent 3–4 inch nodular "ledge" occurs about 11 feet from the base. Grades downward into. . .
3 ft 3 in.	Shale – medium to dark gray, finely laminated, weathers somewhat blocky. The bottom 10 inches or so is almost sheety in 2 inch interbeds. Large pieces of carbonized plant debris are present in the lower 10 inches, in addition to thin (¼ – ½ inch), medium gray, limey fossiliferous interbeds.
1 ft 6 in.	Limestone – medium gray, argillaceous, lenticular, wavy bedded; contains carbonized plant impressions. There are essentially 2 main benches: when the top one is more or less 1 foot thick; the bottom one is more or less 6 inches thick, and vice versa.
3 ft 6+ in.	Siltstone and fine sandstone interbeds; thin silty beds mostly light to medium gray and finely micaceous. Sandstone zones have a medium purple cast; mica is much coarser. There are many fucoid markings (burrows?) up to 4 inches across by more than 15 inches long; a couple of places appear to be large scoured-out plant impressions.
Water level	

The Pennsylvanian limestone sequence might possibly be the Millersville Limestone Member of the Bond Formation.

0.0	32.85+	Leave Stop 7 and TURN LEFT (northeast) before the entrance to the bridge.
0.05	32.9+	STOP: 1-way at Y-intersection. BEAR RIGHT (northeast).

0.15+	33.1	CAUTION: loose gravel.
0.15+	33.25	US 50 overpass. CONTINUE AHEAD (northeast).
0.8	34.05	Cross Otter Pond Ditch. The upland just ahead is the Maumee terrace formed across the relatively flat valley train deposits.
0.25+	34.3+	T-intersection (1170N, 1350E). BEAR LEFT (north).
0.3	34.6+	The slightly rolling character of the surface is due to channel shifting and some small sand dunes.
0.4+	35.0+	STOP: 1-way at T-intersection (1200N, 1400E). TURN LEFT (north).
0.9	35.9+	Prepare to turn right.
0.1+	36.05+	TURN RIGHT (east) at the T-intersection (1300N, 1400E). A sign points to the Mt. Carmel Sand and Gravel Company. Just after making your turn, note that the abandoned gravel pit to the left has been converted to home sites.
0.75	36.8+	TURN LEFT (north) at entrance to the Mt. Carmel Sand and Gravel Company pit and scale house. *You MUST have permission to enter this property.*

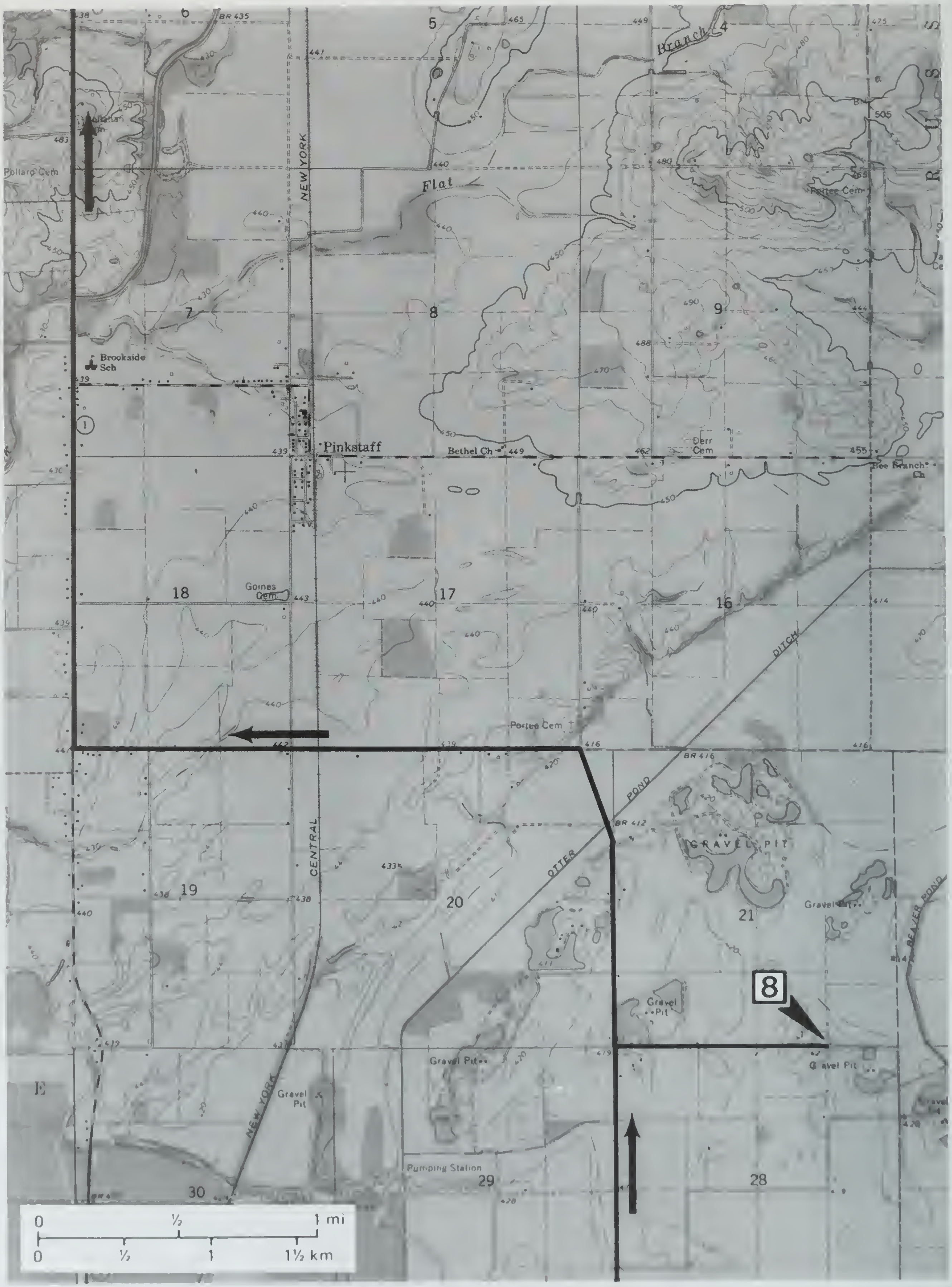
STOP 8 Sand and gravel resources of the field trip area are on view at this site, which is also a good place to collect rocks (office: SW corner, SE SE, Section 21, T4N, R11W. 2nd P.M., Lawrence County; Birds 7.5-Minute Quadrangle [38087G6]).

Lawrenceville Pit

- ***Equipment is off limits. You must stay away.***
- ***Keep back from the edge of the dredged area. The bank could collapse.***

The Wabash River Valley may contain more than l00 feet of sand and gravel where its floor has been most deeply eroded. The sand and gravel that fills this valley is predominantly a late Wisconsinan glacial-age valley train deposit, but remnants of older valley train deposits may be preserved in places. Topographically, this pit appears to be located near the west edge of a low terrace covered with braid bars between abandoned braided stream channels. Apparently, at the time of deposition, meltwater flowing down the valley was so choked with sand and gravel that it divided into several continually shifting channels forming a braided pattern around low relief bars of sand and gravel. The abandoned channels of this braided stream system appear to be at or near the elevation of the Wabash River's floodplain. Its low position in the valley and the absence of a loess cover indicate that it may be the youngest glacial outwash deposit in the valley.

About l½ miles northwest of the plant office, the land surface rises sharply about 20 feet. Drilling records and surficial material data indicate, however, that this is not a sand and gravel outwash terrace, but rather the eroded edge of a slackwater deposit that extends up the Brushy Creek and Embarras River valleys. This deposit formed when the Wabash River Valley was filled with outwash sand and gravel that dammed up the outlets for these streams. The lakes formed behind the dams were partially filled in with lacustrine sand, silt, and clay (Willman and Frye 1970, Lineback 1979).



Pinkstaff
Brookside Sch
Pollard Cem
Goines Cem
Bethel Ch
Derr Cem
Porter Cem
Bee Branch Ch
Flat
Branch
NEW YORK
CENTRAL
NEW YORK
OTTER POND DITCH
BEAVER POND
GRAVEL PIT
Gravel Pit
Pumping Station
8
0 ½ 1 mi
0 ½ 1 1½ km

Sand and gravel is mined entirely by dredges at this location. About 30 feet of material is recovered, up to I0 feet above water and 20 feet below. The overburden consists of about 1 to 1½ feet of sandy top soil that is usually scraped off and stockpiled to be used later during land reclamation. The sand and gravel overlies a hard, liqht gray clay. The company is planning to open a new pit about 0.5 mile to the north, where the sand and gravel deposit is about 45 feet thick.

At this location, the valley train deposit consists mostly of sand with a maximum gravel content of 20% to 25% gravel. The maximum gravel size is about 3 to 4 inches in diameter; the most abundant size is around 2 inches. The dredged material is pumped as a slurry through the pipe from the dredge to the processing plant. As is typical of valley train deposits, the coarser grained and more abundant gravel is present farther upstream in the Wabash River Valley, and the finer grained and less abundant gravel is present downstream. The pump on the dredge is large enough that gravel 8 inches or so in diameter can be recovered. The undersized fine sand, silt, and clay is washed out and pumped to mined-out areas. When these areas are filled in, they are graded to the desired contour and covered with the stockpiled topsoil. These reclaimed areas are excellent for growing soybeans.

The processing plant is capable of producing a variety of fine and coarse construction aggregate products suitable for most uses. Two of their most important products are concrete sand and pea gravel. The gravel may be used in many applications, but is excluded from use in portland cement highway pavement. The qravel causes D-cracking in highway pavement, probably due to its relatively high content of low specific gravity (S.G.) chert (Masters and Evans I987). The sample studied by Masters and Evans was from near the present operation. All samples in this study were from processed gravel stockpiles. The following list of rock types compares those found in this sample with those found in sample 3, a pit in an outwash plain in McHenry County, Illinois, from the same study.

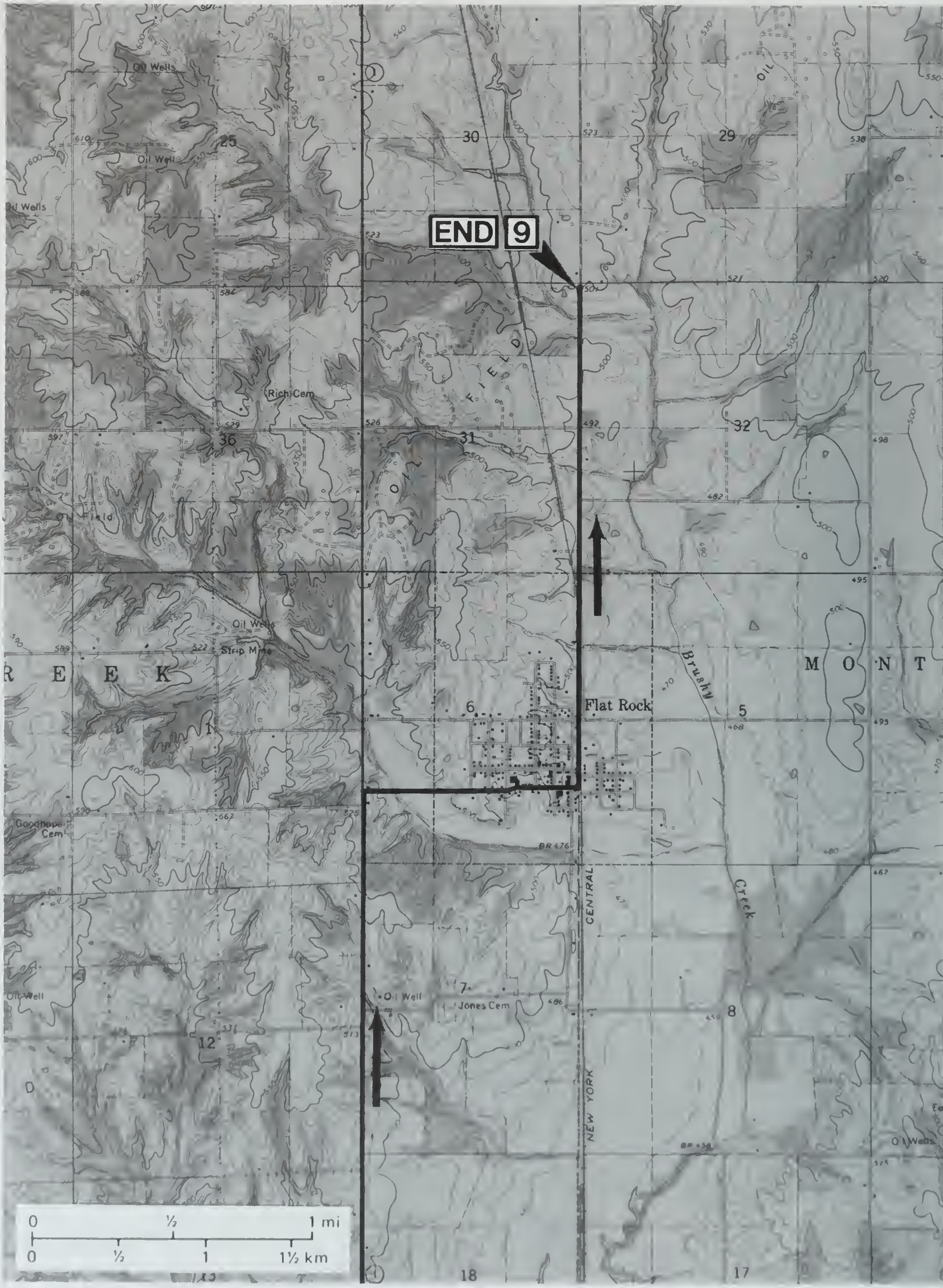
Rock type	Mt. Carmel pit (%)	Sample 3 (%)
Dolomite	22.2	64.8
Limestone	9.4	4.4
Cherty carbonate	6.7	7.4
Weathered carbonate	2.1	3.2
Chert (S.G.)*	18.5+ (2.9)*	7.3+ (0.2)*
Ironstone	0.2	0.3
Shale	0.1	0.3
Sandstone–siltstone	8.2	2.7
Conglomerate	0.1	<0.1
Mafic igneous	4.6	2.8
Felsic igneous	0.6	0.6
Quartz and quartzite	3.6	0.2
Gneisses and schists	9.0	3.2
Metasedimentary	8.3	1.4
Metagraywacke	1.3	1.1
Tillite	2.1	<0.1

Besides indicating the quality of the gravel product, these rock type data also reflect differences in the kinds of rocks carried by different lobes of the continental ice sheet. There is, of course, some mixing due to factors such as one ice lobe eroding the deposits of another. Sample 3, related to the Lake Michigan Lobe, is characterized by relatively high dolomite and low metamorphic rocks.

The Mt. Carmel sample is mainly related to the Lake Erie Lobe and characterized by relatively low dolomite and high metamorphic rocks.

0.0	36.8+	Leave Stop 8 and TURN RIGHT (west) at entrance. Retrace your route to the north-south road (1400E).
0.75	37.55+	STOP: 1-way at T-intersection (1300N, 1400E). TURN RIGHT (north).
0.4	37.95	The area to the left is another example of how land can be used in several ways. The original farmland was mined for sand and gravel. Part of the reclamation effort was to convert it to a recreation area that is now occupied by the Ambraw Sportsmans Club.
0.3	38.25+	CAUTION: loose gravel ahead.
0.05+	38.35+	Cross Otter Pond Ditch.
0.25+	38.6+	STOP: 2-way at the crossroad (1400N, 1400E). TURN LEFT (west).
0.9+	39.55+	Cross abandoned PC railroad grade.
0.05+	39.65+	CAUTION: crossroad (1400N, 1270E). CONTINUE AHEAD (west) on the blacktop.
0.75+	40.4+	STOP: 1-way at T-intersection with SR-1 (1400N, 1200E). TURN RIGHT (north).
1.25+	41.7+	Pinkstaff Road to the right. CONTINUE AHEAD (north).
0.3	42.0+	Cross Brushy Creek.
2.5+	44.5+	Birds Road to the right. CONTINUE AHEAD (north).
1.0+	45.55+	Crawford County line. CONTINUE AHEAD (north).
0.9+	46.6	Cross Sugar Creek.
2.1	48.7	Prepare to turn right ahead.
0.15+	48.85+	TURN RIGHT (east) on Flatrock Road (325N, 1400E).
0.1+	48.95+	Cross the creek.
0.1+	49.1+	CAUTION: enter Village of Flatrock. You are on Second Street.
0.45+	49.6+	STOP: 1-way at Main Street. TURN LEFT (north).
0.2+	49.85+	STOP: 4-way at Baltimore Street. TURN RIGHT (east) and cross the abandoned PC railroad right of way in about 100 feet. In about another 100 feet, TURN LEFT (north) at the T- intersection (350N, 1500E).
1.4+	51.3	Cross the creek and prepare to park ahead.


Sugar
Creek
C R E E K
Nuttle Cem
Oil Wells
Wells
Oil Well
CENTRAL
NEW YORK
CENTRAL
Brushy
Creek
Birds
Oil Well
Hickey Cem
Cotton Cem
0
½
1 mi
0
½
1
1½ km



END 9
Oil Wells
Oil Well
Rich Cem
Oil Field
Strip Mine
R E E K
Flat Rock
Brushy
Creek
M O N T
CENTRAL
NEW YORK
Goodhope Cem
Oil Well
Jones Cem
25
30
29
36
31
32
6
5
7
8
12
18
17
0
½
1 mi
0
½
1
1½ km

0.1+	51.4+	PARK along the road shoulder as far off the pavement as you can safely. Watch for the ditches. CAUTION: limited visibility and fast traffic! Enter the drive on the left (west) side of the road, but ONLY if you have permission!

STOP 9 Tohill Oil Operators working central production unit in southeastern Illinois (entrance: W side of road near SE corner, Section 30, T6N, R11W, 2nd P.M., Crawford County: Flat Rock 7.5-Minute Quadrangle [38087H6]).

This stop at the Tohill central power unit gives you an opportunity to see some equipment used in the early days of recovering oil and still operable today in this part of Illinois. During the first decade of the century, there were few legal limitations on spacing and drilling procedures for oil wells. Because no electricity was available for powering individual pump jacks, many holes were drilled close together so that a number of oil wells could be operated from a single power source. Although as many as 40 wells could be operated from one powerhouse through a connecting system of steel rods or wire cables, the usual number was 25 to 30. The powerhouse contained a natural gas-powered engine (fig. 16a) connected by a large, long belt to a revolving pull wheel (fig. 16b) that provided horizontal movement to the steel pull rods radiating to the various well sites. The gas for the engine was either supplied by wells on the lease or purchased from a neighboring lease or nearby pipeline. The rods are pulled toward the powerhouse by the pull wheel, but the return movement of the rods is at least partially due to gravitational pull on the weight of the sucker rod that extends down into the well. The pumping jacks were constructed of wood or steel (fig. 16c) or a combination of the two.

This powerhouse and its "circle" of wells began operating in 1913. Twelve wells are being serviced by this one engine. The longest distance served by the engine is about 0.75 mile. Some of these wells have enough readily available oil to permit straight or continuous pumping, whereas others have poorer permeability so that only enough oil collects in them to permit periodic pumping each day. Fluid produced from the wells is piped to a serles of wooden storage tanks protected by a board shed (fig. 16d), where the oil and water are separated, about 200 feet east of the power house. The installation is checked several times each day to service the engine, check the pull rods, change them from one well to another, and check the level of oil in the storage tanks.

Some wells here have an average yield of about ¼ barrel of oil per day from the shallow Pennsylvanian sand pay zones. (Note: an "oil field" barrel = 42 standard gallons.) The pay zone in this area may consist of three nonmarine sandstones that occur in the early Pennsylvanian-aged rock sequence, the lowermost sandstone occurring close to the base of the Pennsylvanian. These sandstones, which were deposited by streams between 310 and 300 million years ago, are lenticular and discontinuous throughout the reglon. Not all holes drilled in this area encountered all three sandstone units. The main producing sand here occurs at depths ranging from 930 to 960 feet. The saturated pay zone is about 30 feet thick.

End of field trip.

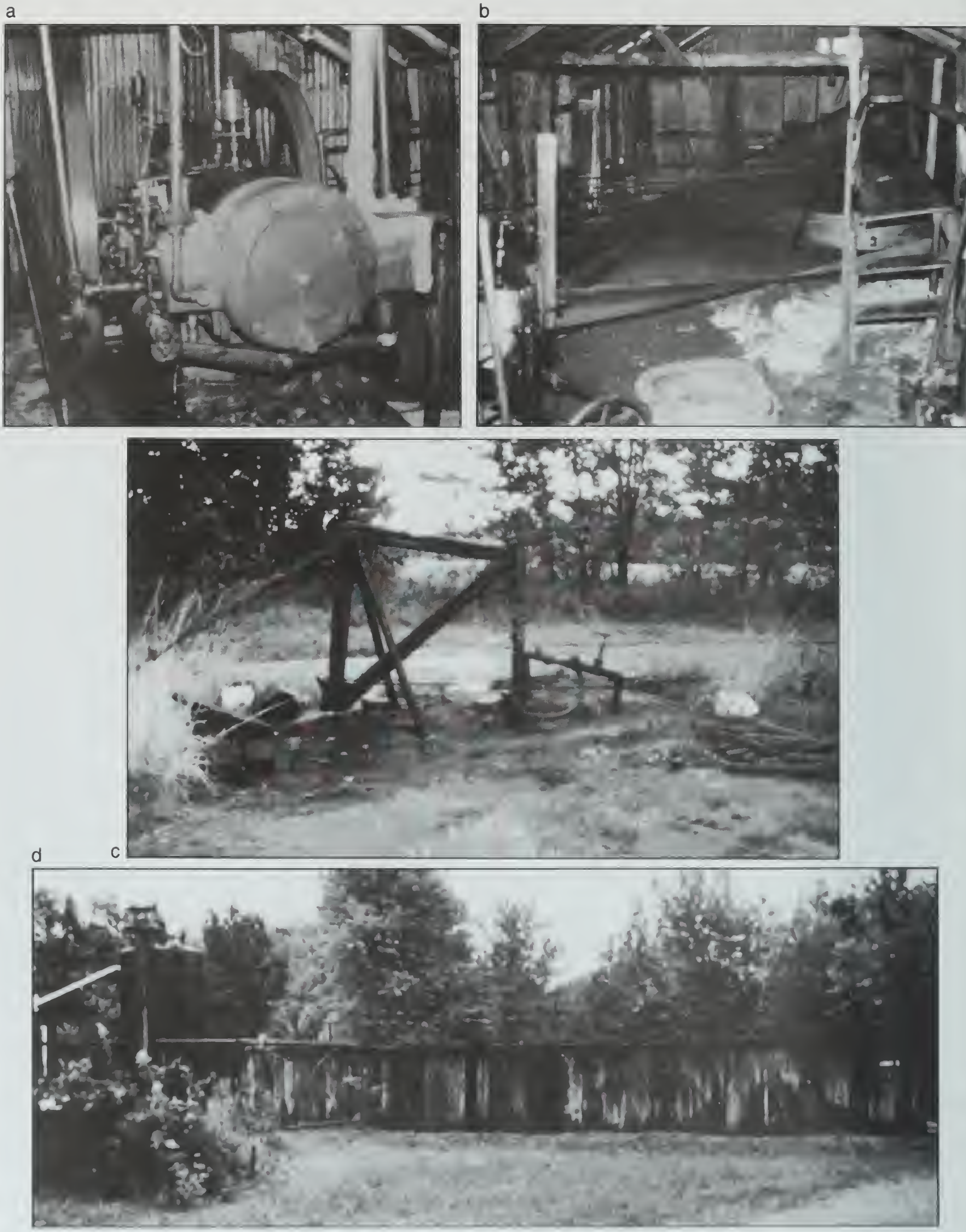


Figure 16 Early oil-producing equipment still operating in southeastern Crawford County in 1993.

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GLOSSARY

Several sources were used for the definitions, but the main reference is the *Glossary of Geology*, edited by Robert L. Bates and Julie A. Jackson (American Geological Institute 1987).

Age — An interval of geologic time; a division of an epoch.

Alluviated valley — One that has been at least partly filled with sand, silt, and mud by flowing water.

Alluvium — A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material deposited during comparatively recent time by a stream or other body of running water as a sorted or semisorted sediment in the bed of a stream or on its floodplain or delta.

Anticline — A convex upward rock fold in which strata have been bent into an arch; the strata on each side of the core of the arch are inclined in opposite directions away from the axis or crest; the core contains rocks older than those on the perimeter of the structure.

Aquifer — A geologic formation that is water-bearing and transmits water from one point to another.

Argillaceous — Largely composed of clay-sized particles or clay minerals.

Bed — A naturally occurring layer of earth material of relatively greater horizontal than vertical extent; it is characterized by a change in physical properties from overlying and underlying materials. It also is the ground upon which any body of water rests or has rested; the land covered by the waters of a stream, lake, or ocean; or the bottom of a watercourse or stream channel.

Bedrock — The solid rock underlying the unconsolidated (non-indurated) surface materials such as soil, sand, gravel, and glacial till.

Bedrock valley — A drainageway eroded into the solid bedrock beneath the surface materials. It may be completely filled with unconsolidated (non-indurated) materials and hidden from view.

Braided stream — A low gradient, low volume stream flowing through an intricate network of interlacing shallow channels that repeatedly merge and divide, and are separated from each other by branch islands or channel bars. Such a stream may be incapable of carrying all of its load.

Calcarenite — Limestone composed of sand-sized grains consisting of more or less worn shell fragments or pieces of older limestone; a clastic limestone.

Calcareous — Containing calcium carbonate ($CaCO_3$); limy.

Calcite — A common rock-forming mineral consisting of $CaCO_3$; it may be white, colorless, or pale shades of gray, yellow, and blue; it has perfect rhombohedral cleavage, appears vitreous, and has a hardness of 3 on the Mohs' scale; it effervesces (fizzes) readily in cold dilute hydrochloric acid. It is the principal constituent of limestone.

Carbonization — The process of concentrating residual carbon through the slow decay and fossilization of an organism or through the progressive changes that occur in the formation of coal.

Chert — Silicon dioxide (SiO_2); a compact, massive rock composed of minute particles of quartz and/or chalcedony; it is similar to flint but lighter in color.

Clastic — Fragmental rock composed of detritus, including broken organic hard parts as well as rock substances of any sort.

Closure — The difference in altitude between the crest of a dome or anticline and the lowest contour that completely surrounds it.

Columnar section — A graphic representation in a vertical column of the sequence and original stratigraphic relations of the rock units.

Conchoidal — (adj.) A fracture surface showing concentric rings or ridges in a shape like a shell or fan. The conchoidal fracture of flint and chert is the property exploited in making sharp stone tools.

Concretion — A hard, compact, commonly rounded (but also disk-shaped or irregular in form) mass or aggregate of mineral matter; usually of a composition widely different from that of the rock in which it is found.

Crystalline — Said of a rock consisting wholly of crystals or fragments of crystals; esp. said of an igneous rock developed through cooling from a molten state and containing no glass, or of a metamorphic rock that has undergone recrystallization.

Cryptocrystalline — (adj.) Exceedingly finely crystalline in texture and appearance with grains essentially indistinguishable even under an ordinary microscope.

Cuesta — An asymmetrical hill or ridge with a long, gentle (back or dip) slope conforming with the resistant bed(s) that form it on one side, and a steep (scarp) slope or cliff on the other; formed by the outcrop of the resistant bed(s).

Delta — A low, nearly flat, alluvial land deposited at or near the mouth of a river where it enters a body of standing water; commonly a triangular or fan-shaped plain sometimes extending beyond the general trend of the coastline.

Detritus — Material produced by mechanical disintegration.

Diamictite — A comprehensive, nongenetic term for a nonsorted or poorly sorted, noncalcareous, terrigenous sedimentary rock that contains a wide range of particle sizes, such as a rock with sand and/or larger particles in a muddy matrix; e.g. a tillite or a pebbly mudstone.

Diamicton — A general term for the nonlithified equivalent of a diamictite; e.g. a till.

Dike — A tabular, intrusive body of igneous rock that cuts across the structure of stratified, metamorphosed, or igneous rocks.

Dip slope — An inclined land surface that is parallel to the dip of the underlying stratified rocks.

Disconformity — An *unconformity* marked by a distinct erosion-produced, irregular, uneven surface of appreciable relief between parallel strata below and above the break; sometimes represents a considerable interval of nondeposition.

Dolomite — A mineral, calcium-magnesium carbonate ($CaMg(CO_3)_2$; applied to those sedimentary rocks that are composed largely of the mineral dolomite; it is also precipitated directly from seawater. It is white, colorless, or tinged yellow, brown, pink, or gray, and has perfect rhombohedral cleavage; it appears pearly to vitreous, and effervesces feebly in cold dilute hydrochloric acid.

Distributary — An irregular, divergent stream flowing away from the main stream and not returning to it, as in a delta.

Dolomite — A mineral, calcium-magnesium carbonate ($CaMg(CO_3)_2$; applied to those sedimentary rocks that are composed largely of the mineral dolomite; it is also precipitated directly from seawater. It is white, colorless, or tinged yellow, brown, pink, or gray, and has perfect rhombohedral cleavage; it appears pearly to vitreous, and effervesces feebly in cold dilute hydrochloric acid.

Dome — A roughly symmetrical upfold (anticline) in which strata are inclined in all directions away from a central point.

Drift — All rock material transported by a glacier and deposited either directly by the ice or reworked and deposited by meltwater streams and/or the wind.

Driftless Area — A 10,000 square mile area in northeastern Iowa, southwestern Wisconsin, and northwestern Illinois where the absence of glacial drift indicates that the area may not have been glaciated during the Pleistocene.

Earthquake — A sudden motion or trembling in the earth caused by the abrupt release of slowly accumulated potential energy (like that in a compressed spring) through the breaking of a rock body to form a fault, or slippage along a preexisting fault plane in the rock body.

End moraine — A ridge-like or series of ridge-like accumulations of drift that develop along the margin of an actively flowing glacier at any given time; a moraine that has been deposited at the lower or outer end of a glacier.

Eon — The largest division of geologic time; it consists of two or more eras.

Epoch — An interval of geologic time; a division of a period.

Era — A unit of geologic time that is next in magnitude beneath an eon; consists of two or more periods.

Esker — Ridges, usually sinuous, of stratified (layered) drift (sand and gravel) in areas of ground moraine. They are deposited by, and mark the channels of, meltwater streams that flowed in, on, or under a glacier.

Estuary — The seaward end or the widened funnel-shaped tidal mouth of a river valley where it meets the sea; the part of a river where fresh water and sea water mix and where the effects of ocean tides are evident.

Fault — A fracture surface or zone in earth materials along which there has been vertical and/or horizontal displacement or movement of the strata on both sides relative to one another.

Ferruginous — Pertaining to or containing iron, e.g., a sandstone that is cemented with iron oxide.

Fissile — Capable of being easily split along closely spaced planes; laminae generally less than 2 millimeters thick.

Floodplain — The surface or strip of relatively smooth land that lies adjacent to a stream channel and has been produced by stream erosion and deposition; the area covered with water when the stream overflows its banks at times of high water; it is built of alluvium carried by the stream during floods and deposited in the sluggish water beyond the influence of the swiftest current.

Fluvial — Of or pertaining to a river or rivers.

Fluviolacustrine — Pertains to sedimentation partly in lake water and partly in streams, or to sediments deposited under alternating or overlapping lacustrine and fluvial conditions.

Formation — The basic rock unit distinctive enough to be readily recognizable in the field and widespread and thick enough to be plotted on a map. It describes the strata, such as limestone, sandstone, shale, or combinations of these and other rock types; formations have formal names, such as Joliet Formation or St. Louis Limestone (Formation), which are usually derived from geographic localities.

Geology — (a) The science of the earth; it includes, in a large sense, all acquired or possible knowledge of the natural phenomena on and within the globe. (b) Earth science including physical geology and geophysics; the history of the earth; stratigraphy and paleontology; mineralogy; petrology; and engineering, mining, and petroleum geology.

Geologic column — a chart that shows the subdivisions of part or all of geologic time or the sequence of stratigraphic units (oldest at the bottom and youngest at the top) of a given place or region.

Geomorphology — A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of land forms.

Geophysics — Study of the earth as a planet, generally by employing quantitative measurements of phenomena such as the earth's electrical, magnetic and gravity fields, or the movement of energy through the rocks..

Glacier — A large, slow-moving mass of ice, at least in partly on land. The Arctic ice cap of the earth is not a glacier because it is mostly floating on the ocean surface. The Antarctic ice cap is a glacier.

Graben — An elongate, relatively depressed crustal unit or block that is bounded by faults on its long sides. It is a structural form that may or may not be geomorphologically expressed as a rift valley.

Gradient — A part of a surface feature of the earth that slopes upward or downward; a slope, as of a stream channel or of a land surface. In engineering, the synonymous term is *grade.*

Ground moraine — A sheet-like accumulation of glacial drift, principally till, deposited beneath a glacier to form an extensive area of low relief devoid of transverse linear features.

Groundwater — Water that is present below the ground surface in the soil and rocks of the earth's outer crust. Geologists generally restrict the term to that part of the subsurface water that is within the zone in which rocks are saturated with water (i.e. below the water table).

Group — A geologic rock unit consisting of two or more formations.

Hiatus — A gap in the sedimentary record; may or may not be associated with removal of sediment by erosion (signifies an unconformity).

Hydrogeology — The science that deals with subsurface waters and related geologic aspects of surface waters.

Ice cap — A dome-shaped or plate-like cover of perennial ice and snow covering the summit of a mountain so that no peaks emerge through it, or covering a flat landmass such as an Arctic island...and having an area less than 50,000 square kilometers; it is considerably smaller than an *ice sheet.*

Ice sheet — A glacier of considerable thickness and more than 50,000 square kilometers in area, forming a continuous cover of ice and snow over a land surface...and not confined by the underlying topography; a *continental glacier.*

Igneous — Said of a rock or mineral that solidified from molten or partly molten material, i.e., from magma.

Indurated — A compact rock or soil hardened by the action of pressure, cementation, and especially heat.

Joint — A fracture or crack in rocks along which there has been no movement of the opposing sides.

Kame — A hill, mound, knob, or hummock formed of poorly sorted and stratified sand and/or gravel depoisted against the terminal margin of a melting glacier by a subglacial or englacial meltwater stream.

Karst — A type of topography formed in areas underlain by limestone, dolomite, or gypsum. Karst topography is characterized by sinkholes separated by steep ridges or irregular hills. Tunnels and caves resulting from solution by groundwater honeycomb the subsurface.

Lacustrine — Produced by or belonging to a lake.

Laurasia — A combination of Laurentia, a paleogeographic term for the Canadian Shield and its surroundings, and Eurasia. It is the protocontinent of the Northern Hemisphere, corresponding to Gondwana in the Southern Hemisphere, from which the present continents of the Northern Hemisphere have been derived by separation and continental displacement. The hypothetical supercontinent from which both were derived is *Pangea*. The protocontinent included most of North America, Greenland, and most of Eurasia, excluding India. The main zone of separation was in the North Atlantic, with a branch in Hudson Bay; geologic features on opposite sides of these zones are very similar.

Lava — A general term for molten material extruded onto the earth's surface from a volcano; also, applies to the rock that solidified from the extyruded material.

Limestone — A sedimentary rock consisting primarily of calcium carbonate (the mineral, calcite).

Lithify — To change to stone, or to petrify; esp. to consolidate from a loose sediment to a solid rock.

Lithology — The description of rocks on the basis of color, structures, mineral composition, and grain size; the physical character of a rock.

Local relief — The vertical difference in elevation between the highest and lowest points of a land surface within a specified horizontal distance or in a limited area.

Loess — A homogeneous, unstratified deposit of silt deposited by the wind.

Magma — Naturally occurring mobile rock material, generated within the earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes.

Meander — One of a series of somewhat regular, sharp, sinuous curves, bends, loops, or turns produced by a stream, particularly in its lower course where its channel swings from side to side across its valley bottom.

Meander scars — Crescent, concave marks along a river's floodplain marking the positions of abandoned meanders. Although generally filled with sediments and vegetation, they form low swales and may contain water during wet seasons. Often invisible from the ground, they make striking patterns when viewed from the air, and may also be readily apparent on topographic maps.

Member — A rock-stratigraphic unit of subordinate rank, comprising some specially developed part of a varied formation (e.g., a subdivision of local extent only, or a unit with the same color, hardness, composition, and other rock properties that distinguish it from adjacent units in the formation). It may be formally defined and named, informally named, or unnamed; it is not necessarily mappable.

Metamorphic rock — Any rock derived from preexisting rocks by mineralogical, chemical, and structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment at depth in the earth's crust (gneisses, schists, marbles, quartzites).

Metamorphism — The processes by which metamorphic rocks are formed and the changes induced by those processes in preexisting rock. In general, metamorphism does not alter the chemical composition of the preexisiting rock either by introducing new material or by extracting material. The processes of metamorphism only rearrange the preexisting chemical elements in the rock from one set of minerals to a new set of minerals more closely in equilibrium with the new temperature and pressure conditions imposed on the rock.

Mica — Any of the members of a group of minerals known as phyllosilicates (having sheet-like structures) that can be easily split apart into thin, tough, slightly bendable sheets. The micas are common minerals in igneous and metamorphic rocks and can vary from colorless to to yellow, green, brown, or black. The most common members of the family are muscovite (colorless to pale yellow) and biotite (dark brown to black).

Monocline — Strata inclined in a single direction, such as a step-like fold or downwarp.

Moraine — A mound, ridge, or other distinct accumulation of...glacial drift, predominantly till, deposited...in a variety of topographic landforms that are independent of control by the surface on which the drift lies.

Outwash — Stratified drift (clay, silt, sand, gravel) deposited by meltwater streams in channels, deltas, and glacial lakes, and on outwash plains and floodplains.

Outwash plain — The surface of a broad body of outwash formed in front of a glacier.

Overburden — The upper part of a sedimentary deposit, compressing and consolidating the material below; or barren rock material overlying a mineral deposit.

Pangea — A hypothetical supercontinent supposed by many geologists to have existed very early in the geologic past, and to have combined all the continental crust from which the present continents were derived by fragmentation and movement away from each other by means of some form of continental displacement. During an intermediate stage of the fragmentation, between the existence of Pangea and that of the present, widely separated continents, Pangea was supposed to have split into two large fragments, *Laurasia* on the north and *Gondwana* on the south. The proto-ocean around Pangea has been termed *Panthalassa*. Other geologists, while accepting the former existence of Laurasia and Gondwana, are reluctant to concede the existence of an original Pangea; in fact, the early (Paleozoic or older) history of continental displacement remains largely undeciphered.

Period — An interval of geologic time; a division of an era.

Physiography — The study and classification of the surface features of Earth on the basis of similarities in geologic structure and the history of geologic changes.

Physiographic province (or division) — (a) A region, all parts of which are similar in geologic structure and climate and which has consequently had a unified geologic history; (b) a region whose pattern of relief features or landforms differs significantly from that of adjacent regions.

Proglacial — (adj.) In front of a glacier.

Prograding (shoreline) — A shoreline that is being built forward or outward into a sea or lake by deposition and accumulation of sediments.

Rank — A coal classification based on degree of metamorphism.

Relief — (a) A term used loosely for the actual physical shape, configuration, or general uneveness of a part of the earth's surface, considered with reference to variations of height and slope or to irregularities of the land surface; the elevations or differences in elevation, considered collectively, of a land surface (frequently confused with topography). (b) The vertical difference in elevation between the hilltops or mountain summits and the lowlands or valleys of a given region: "high relief" has great variation; "low relief" has little variation.

Sediment — Solid fragmental material, either inorganic or organic, that originates from weathering of rocks and is transported by, suspended in, or deposited by air, water, or ice, or that is accumulated by other natural agents, such as chemical precipitation from solution or secretion from organisms, and that forms in layers on the earth's surface at ordinary temperatures in a loose, unconsolidated form; e.g, sand, gravel, silt, mud, till, loess, alluvium.

Sedimentary rock — A rock resulting from the consolidation of loose sediment that has accumulated in layers.

Series — A geologic time-stratigraphic unit; the strata deposited during an epoch; a division of a system.

Sinkhole — A circular depression formed by solution in areas underlain by soluble rocks, most commonly limestone and dolomite. Sinkholes are characteristic in areas of karst topography.

Sluiceway — An overflow channel.

Stage, substage — Geologic time-stratigraphic units; the strata formed during an age or subage, respectively.

Stratigraphy — the study, definition, and description of major and minor natural divisions of rocks, especially the study of the form, arrangement, geographic distribution, chronologic succession, classification, correlation, and mutual relationships of rock strata.

Stratigraphic unit — A stratum or body of strata recognized as a unit in the classification of the rocks of the earth's crust with respect to any specific rock character, property, or attribute or for any purpose such as description, mapping, and correlation.

Stratum, plural strata — A tabular or sheet-like mass, or a single and distinct layer, of homogeneous or gradational sedimentary material of any thickness, visually separable from other layers above and below by a discrete change in character of the material deposited or by a sharp physical break in deposition, or by both; a sedimentary *bed.*

Stylolite — A surface or contact, usually occurring in homogeneous carbonate rocks...that is marked by an irregular and interlocking penetration of the two sides; the columns, pits, and teeth-like projections on one side fit into their counterparts on the other. As usually seen in cross section, it resembles a suture or the tracing of a stylus. The seam is characterized by a concentraion of insoluble constituents of the rock...and is commonly parallel to the bedding.

Syncline — A concave upward rock fold in which rocks are bowed down and dip inward from both sides toward the axis. The core contains younger rocks than does the perimeter of the structure; the opposite of an anticline.

System — the largest, fundamental geologic time-stratigraphic unit; the strata of a system were deposited during a period of geologic time.

Tectonic — pertaining to the global forces involved in, or the resulting structures or features of the earth's movements.

Till — Unconsolidated, nonsorted, unstratified drift deposited by and underneath a glacier and consisting of a heterogenous mixture of different sizes and kinds of rock fragments.

Till plain — The wavey surface of low relief in the area underlain by ground moraine.

Topography — The natural or physical surface features of a region, considered collectively as to form; the features revealed by the contour lines of a map.

Type section — The original sequence of strata as described for a given locality or area. It serves as an objective standard with which spatially separated outcrops of a stratigraphic unit can be compared for purposes of identification. Type sections preferably show the maximum thickness of a stratigrahic unit and are completely exposed, or at least show the top and bottom contacts of a unit. There is only one type section for any stratigraphic unit, but additional *reference sections* may be described.

Unconformity — A surface of erosion or nondeposition that separates younger strata from older strata; most unconformities indicate intervals of time when former areas of the sea bottom were temporarily raised above sea level.

Valley trains — The accumulations of outwash deposited by rivers in the valleys downstream from a glacier.

PLEISTOCENE GLACIATIONS IN ILLINOIS

Origin of the Glaciers

During the past million years or so, an interval of time called the Pleistocene Epoch, most of the northern hemisphere above the 50th parallel has been repeatedly covered by glacial ice. The cooling of the earth's surface, a prerequisite for glaciation, began at least 2 million years ago. On the basis of evidence found in subpolar oceans of the world (temperature-dependent fossils and oxygen-isotope ratios), a recent proposal has been made to recognize the beginning of the Pleistocene at 1.6 million years ago. Ice sheets formed in sub-arctic regions many times and spread outward until they covered the northern parts of Europe and North America. In North America, early studies of the glacial deposits led to the model that four glaciations could explain the observed distribution of glacial deposits. The deposits of a glaciation were separated from each other by the evidence of intervals of time during which soils formed on the land surface. In order of occurrence from the oldest to the youngest, they were given the names Nebraskan, Kansan, Illinoian, and Wisconsinan Stages of the Pleistocene Epoch. Work in the last 30 years has shown that there were more than four glaciations but the actual number and correlations at this time are not known. Estimates that are gaining credibility suggest that there may have been about 14 glaciations in the last one million years. In Illinois, estimates range from 4 to 8 based on buried soils and glacial deposits. For practical purposes, the previous four glacial stage model is functional, but we now know that the older stages are complex and probably contain more than one glaciation. Until we know more, all of the older glacial deposits, including the Nebraskan and Kansan will be classified as pre-Illinoian. The limits and times of the ice movement in Illinois are illustrated in the following pages by several figures.

The North American ice sheets developed when the mean annual temperature was perhaps 4° to 7°C (7° to 13°F) cooler than it is now and winter snows did not completely melt during the summers. Because the time of cooler conditions lasted tens of thousands of years, thick masses of snow and ice accumulated to form glaciers. As the ice thickened, the great weight of the ice and snow caused them to flow outward at their margins, often for hundreds of miles. As the ice sheets expanded, the areas in which snow accumulated probably also increased in extent.

Tongues of ice, called lobes, flowed southward from the Canadian centers near Hudson Bay and converged in the central lowland between the Appalachian and Rocky Mountains. There the glaciers made their farthest advances to the south. The sketch below shows several centers of flow, the general directions of flow from the centers, and the southern extent of glaciation. Because Illinois lies entirely in the central lowland, it has been invaded by glaciers from every center.

Effects of Glaciation

Pleistocene glaciers and the waters melting from them changed the landscapes they covered. The glaciers scraped and smeared the landforms they overrode, leveling and filling many of the minor valleys and even some of the larger ones. Moving ice carried colossal amounts of rock and earth, for much of what the glaciers wore off the ground was kneaded into the moving ice and carried along, often for hundreds of miles.

The continual floods released by melting ice entrenched new drainageways, deepened old ones, and then partly refilled both with sediments as great quantities of rock and earth were carried beyond the glacier fronts. According to some estimates, the amount of water drawn from the sea and changed into ice during a glaciation was enough to lower the sea level from 300 to 400 feet below present level. Consequently, the melting of a continental ice sheet provided a tremendous volume of water that eroded and transported sediments.

In most of Illinois, then, glacial and meltwater deposits buried the old rock-ribbed, low, hill-and-valley terrain and created the flatter landforms of our prairies. The mantle of soil material and the buried deposits of gravel, sand, and clay left by the glaciers over about 90 percent of the state have been of incalculable value to Illinois residents.

Glacial Deposits

The deposits of earth and rock materials moved by a glacier and deposited in the area once covered by the glacier are collectively called **drift**. Drift that is ice-laid is called **till**. Water-laid drift is called **outwash**.

Till is deposited when a glacier melts and the rock material it carries is dropped. Because this sediment is not moved much by water, a till is unsorted, containing particles of different sizes and compositions. It is also stratified (unlayered). A till may contain materials ranging in size from microscopic clay particles to large boulders. Most tills in Illinois are pebbly clays with only a few boulders. For descriptive purposes, a mixture of clay, silt, sand and boulders is called **diamicton**. This is a term used to describe a deposit that could be interpreted as till or a mass wasting product.

Tills may be deposited as **end moraines**, the arc-shaped ridges that pile up along the glacier edges where the flowing ice is melting as fast as it moves forward. Till also may be deposited as **ground moraines**, or **till plains**, which are gently undulating sheets deposited when the ice front melts back, or retreats. Deposits of till identify areas once covered by glaciers. Northeastern Illinois has many alternating ridges and plains, which are the succession of end moraines and till plains deposited by the Wisconsinan glacier.

Sorted and stratified sediment deposited by water melting from the glacier is called **outwash**. Outwash is bedded, or layered, because the flow of water that deposited it varied in gradient, volume, velocity, and direction. As a meltwater stream washes the rock materials along, it sorts them by size—the fine sands, silts, and clays are carried farther downstream than the coarser gravels and cobbles. Typical Pleistocene outwash in Illinois is in multilayered beds of clays, silts, sands, and gravels that look much like modern stream deposits in some places. In general, outwash tends to be coarser and less weathered, and alluvium is most often finer than medium sand and contains variable amounts of weathered material.

Outwash deposits are found not only in the area covered by the ice field but sometimes far beyond it. Meltwater streams ran off the top of the glacier, in crevices in the ice, and under the ice. In some places, the cobble-gravel-sand filling of the bed of a stream that flowed in the ice is preserved as a sinuous ridge called an **esker**. Some eskers in Illinois are made up of sandy to silty deposits and contain mass wasted diamicton material. Cone-shaped mounds of coarse outwash, called **kames**, were formed where meltwater plunged through crevasses in the ice or into ponds on the glacier.

The finest outwash sediments, the clays and silts, formed bedded deposits in the ponds and lakes that filled glacier-dammed stream valleys, the sags of the till plains, and some low, moraine-diked till plains. Meltwater streams that entered a lake rapidly lost speed and also quickly dropped the sands and gravels they carried, forming deltas at the edge of the lake. Very fine sand and silts were commonly redistributed on the lake bottom by wind-generated currents, and the clays, which stayed in suspension longest, slowly settled out and accumulated with them.

Along the ice front, meltwater ran off in innumerable shifting and short-lived streams that laid down a broad, flat blanket of outwash that formed an **outwash plain**. Outwash was also carried away from the glacier in valleys cut by floods of meltwater. The Mississippi, Illinois, and Ohio Rivers occupy valleys that were major channels for meltwaters and were greatly widened and deepened during times of the greatest meltwater floods. When the floods waned, these valleys were partly filled with outwash far beyond the ice margins. Such outwash deposits, largely sand and gravel, are known as **valley trains**. Valley train deposits may be both extensive and thick. For instance, the long valley train of the Mississippi Valley is locally as much as 200 feet thick.

Loess, Eolian Sand and Soils

One of the most widespread sediments resulting from glaciation was carried not by ice or water but by wind. **Loess** is the name given to windblown deposits dominated by silt. Most of the silt was derived from wind erosion of the valley trains. Wind action also sorted out **eolian sand** which commonly formed **sand dunes** on the valley trains or on the adjacent uplands. In places, sand dunes have migrated up to 10 miles away from the principle source of sand. Flat areas between dunes are generally underlain by eolian **sheet sand** that is commonly reworked by water action. On uplands along the major valley trains, loess and eolian sand are commonly interbedded. With increasing distance from the valleys, the eolian sand pinches out, often within one mile.

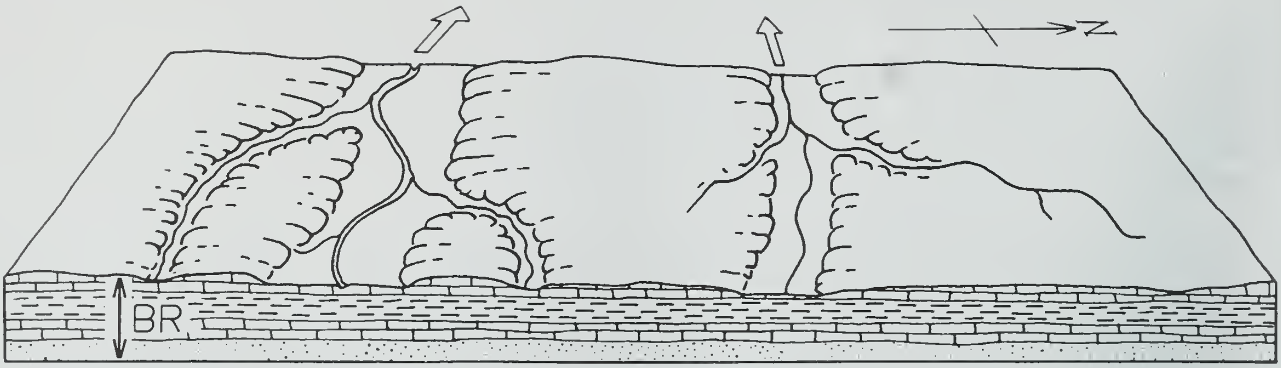
Eolian deposition occurred when certain climatic conditions were met, probably in a seasonal pattern. Deposition could have occurred in the fall, winter or spring season when low precipitation rates and low temperatures caused meltwater floods to abate, exposing the surfaces of the valley trains and permitting them to dry out. During Pleistocene time, as now, west winds prevailed, and the loess deposits are thickest on the east sides of the source valleys. The loess thins rapidly away from the valleys but extends over almost all the state.

Each Pleistocene glaciation was followed by an interglacial stage that began when the climate warmed enough to melt the glaciers and their snowfields. During these warmer intervals, when the climate was similar to that of today, drift and loess surfaces were exposed to weather and the activities of living things. Consequently, over most of the glaciated terrain, soils developed on the Pleistocene deposits and altered their composition, color, and texture. Such soils were generally destroyed by later glacial advances, but some were buried. Those that survive serve as "key beds," or stratigraphic markers, and are evidence of the passage of a long interval of time.

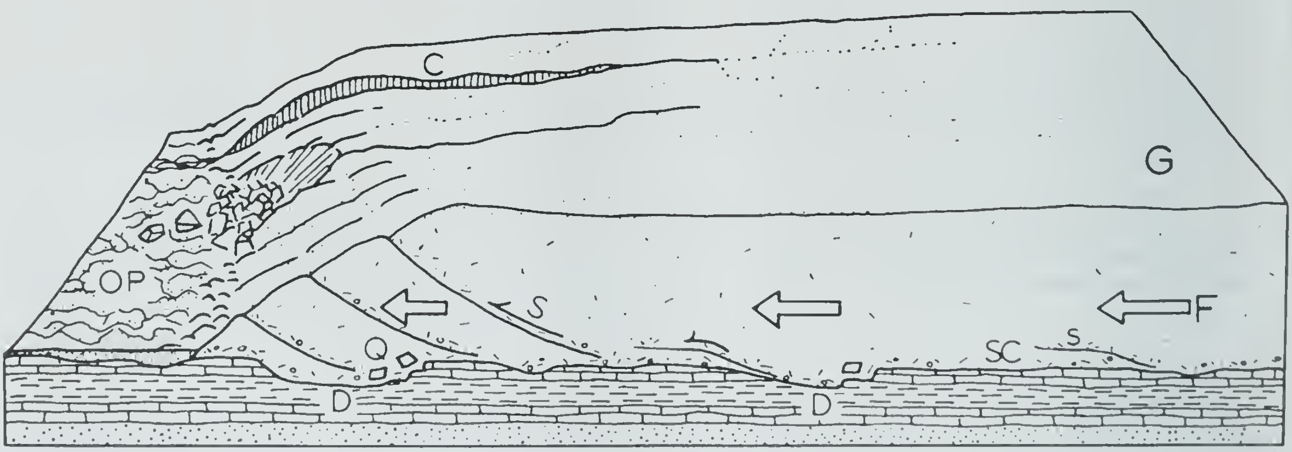
Glaciation in a Small Illinois Region

The following diagrams show how a continental ice sheet might have looked at various stages as it moved across a small region in Illinois. They illustrate how it could change the old terrain and create a landscape like the one we live on. To visualize how these glaciers looked, geologists study the landforms and materials left in the glaciated regions and also the present-day mountain glaciers and polar ice caps.

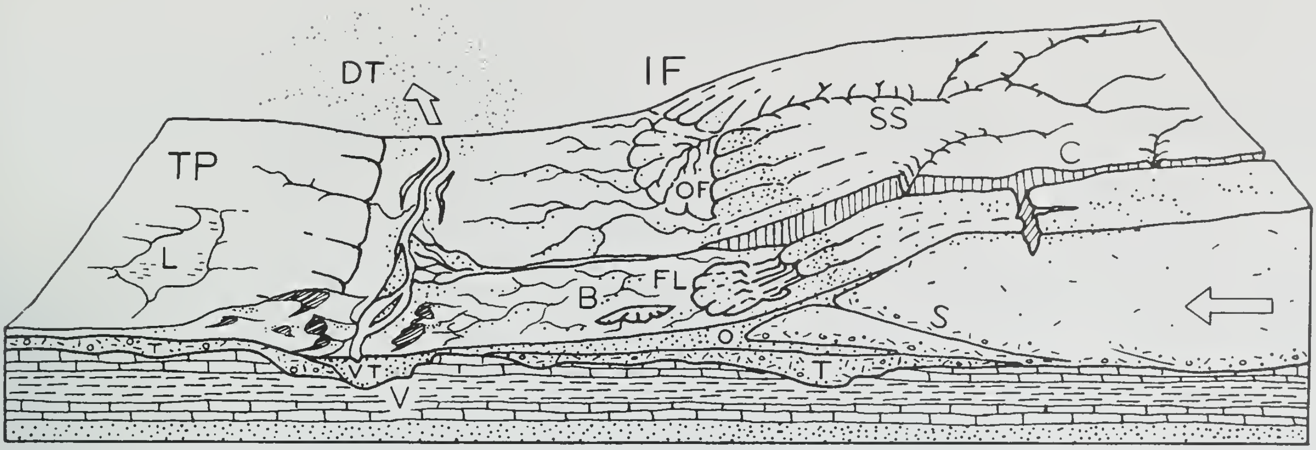
The block of land in the diagrams is several miles wide and about 10 miles long. The vertical scale is exaggerated—layers of material are drawn thicker and landforms higher than they ought to be so that they can be easily seen.



1. **The Region Before Glaciation** — Like most of Illinois, the region illustrated is underlain by almost flat-lying beds of sedimentary rocks—layers of sandstone ( ), limestone ( ), and shale ( ). Millions of years of erosion have planed down the bedrock (BR), creating a terrain of low uplands and shallow valleys. A residual soil weathered from local rock debris covers the area but is too thin to be shown in the drawing. The streams illustrated here flow westward and the one on the right flows into the other at a point beyond the diagram.



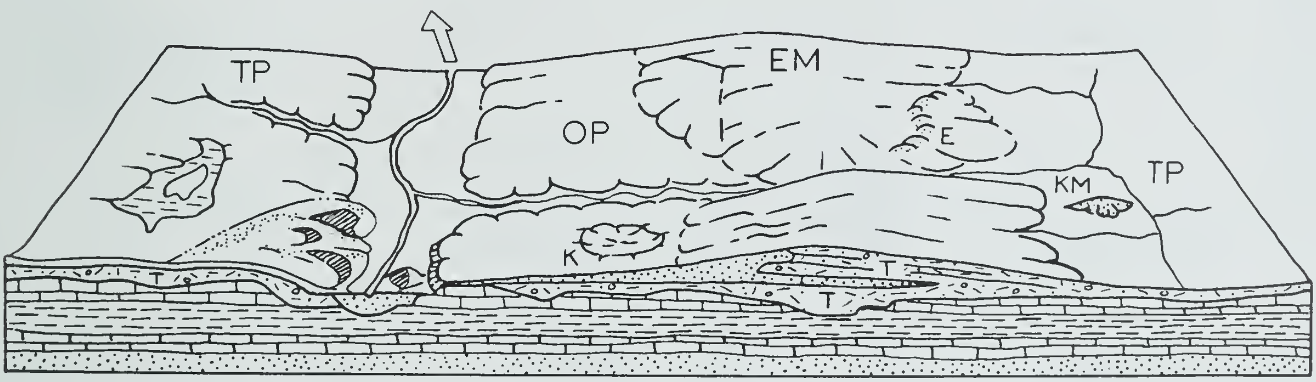
2. **The Glacier Advances Southward** — As the Glacier (G) spreads out from its ice snowfield accumulation center, it scours (SC) the soil and rock surface and quarries (Q)—pushes and plucks up—chunks of bedrock. The materials are mixed into the ice and make up the glacier's "load." Where roughnesses in the terrain slow or stop flow (F), the ice "current" slides up over the blocked ice on innumerable shear planes (S). Shearing mixes the load very thoroughly. As the glacier spreads, long cracks called "crevasses" (C) open parallel to the direction of ice flow. The glacier melts as it flows forward, and its meltwater erodes the terrain in front of the ice, deepening (D) some old valleys before ice covers them. Meltwater washes away some of the load freed by melting and deposits it on the outwash plain (OP). The advancing glacier overrides its outwash and in places scours much of it up again. The glacier may be 5000 or so feet thick, and tapers to the margin, which was probably in the range of several hundred feet above the old terrain. The ice front advances perhaps as much as a third of a mile per year.



3. **The Glacier Deposits an End Moraine** — After the glacier advances across the area, the climate warms and the ice begins to melt as fast as it advances. The ice front (IF) is now stationary, or fluctuating in a narrow area, and the glacier is depositing an end moraine.

As the top of the glacier melts, some of the sediment that is mixed in the ice accumulates on top of the glacier. Some is carried by meltwater onto the sloping ice front (IF) and out onto the plain beyond. Some of the debris slips down the ice front in a mudflow (FL). Meltwater runs through the ice in a crevasse (C). A supraglacial stream (SS) drains the top of the ice, forming an outwash fan (OF). Moving ice has overridden an immobile part of the front on a shear plane (S). All but the top of a block of ice (B) is buried by outwash (O).

Sediment from the melted ice of the previous advance (figure 2) remains as a till layer (T), part of which forms the till plain (TP). A shallow, marshy lake (L) fills a low place in the plain. Although largely filled with drift, the valley (V) remains a low spot in the terrain. As soon as the ice cover melts, meltwater drains down the valley, cutting it deeper. Later, outwash partly refills the valley: the outwash deposit is called a valley train (VT). Wind blows dust (DT) off the dry floodplain. The dust will form a loess deposit when it settles. Sand dunes (D) form on the south and east sides of streams.



4. **The Region after Glaciation** — As the climate warms further, the whole ice sheet melts, and glaciation ends. The end moraine (EM) is a low, broad ridge between the outwash plain (OP) and till plains (TP). Run-off from rains cuts stream valleys into its slopes. A stream goes through the end moraine along the channel cut by the meltwater that ran out of the crevasse in the glacier.

Slopewash and vegetation are filling the shallow lake. The collapse of outwash into the cavity left by the ice block's melting has made a kettle (K). The outwash that filled a tunnel draining under the glacier is preserved in an esker (E). The hill of outwash left where meltwater dumped sand and gravel into a crevasse or other depression in the glacier or at its edge is a kame (KM). A few feet of loess covers the entire area but cannot be shown at this scale.

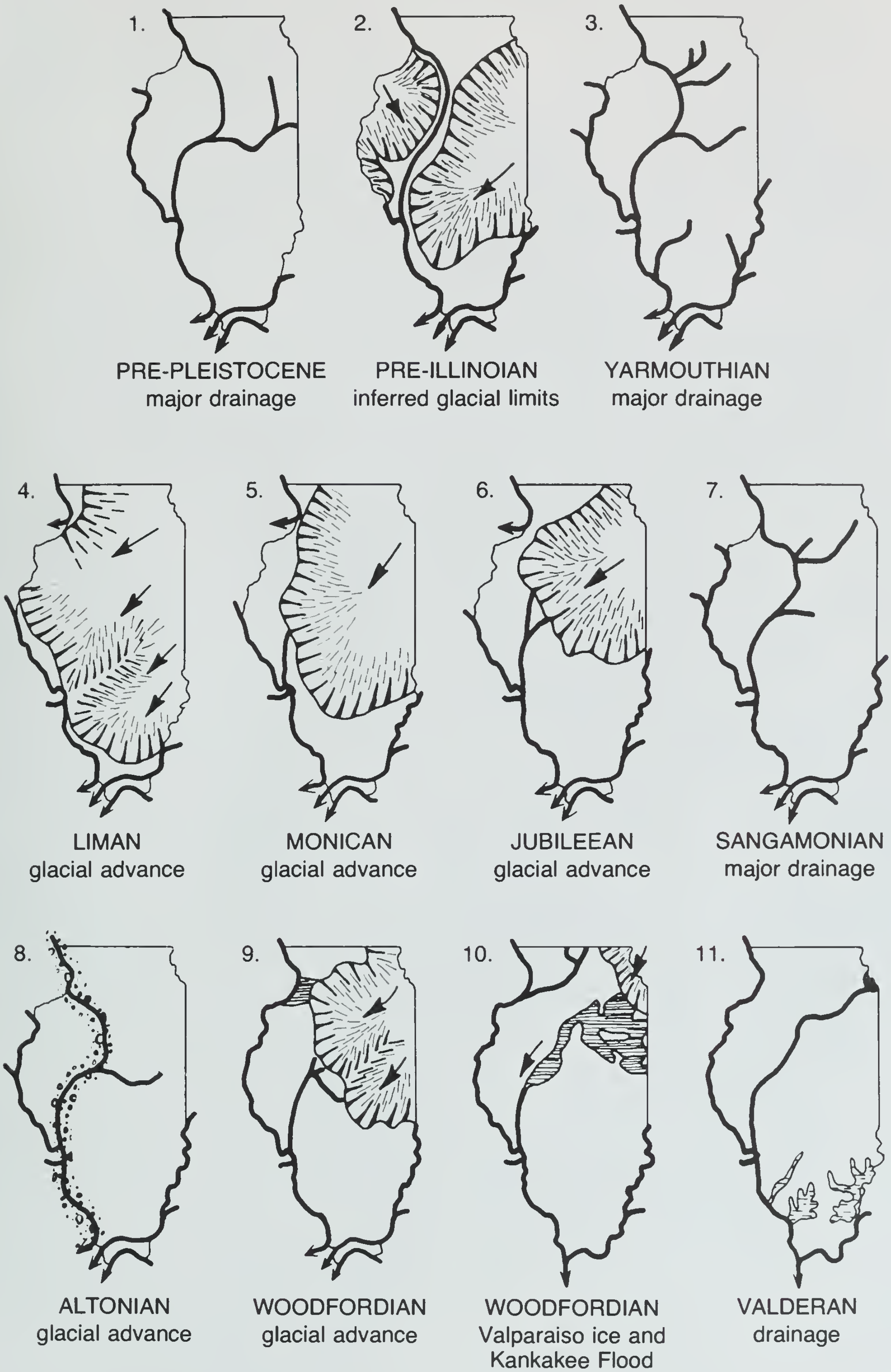
TIME TABLE OF PLEISTOCENE GLACIATION

		STAGE	SUBSTAGE	NATURE OF DEPOSITS	SPECIAL FEATURES
QUATERNARY		HOLOCENE (interglacial)	Years Before Present	Soil, youthful profile of weathering, lake and river deposits, dunes, peat	
			10,000		
	Pleistocene	WISCONSINAN (glacial)	Valderan	Outwash, lake deposits	Outwash along Mississippi Valley
			11,000		
			Twocreekan	Peat and alluvium	Ice withdrawal, erosion
			12,500		
		late	Woodfordian	Drift, loess, dunes, lake deposits	Glaciation; building of many moraines as far south as Shelbyville; extensive valley trains, outwash plains, and lakes
			25,000		
		mid	Farmdalian	Soil, silt, and peat	Ice withdrawal, weathering, and erosion
			28,000		
		early	Altonian	Drift, loess	Glaciation in Great Lakes area, valley trains along major rivers
			75,000		
		SANGAMONIAN (interglacial)		Soil, mature profile of weathering	Important stratigraphic marker
			125,000		
		ILLINOIAN (glacial)	Jubileean	Drift, loess, outwash	Glaciers from northeast at maximum reached Mississippi River and nearly to southern tip of Illinois
			Monican	Drift, loess, outwash	
			Liman	Drift, loess, outwash	
			300,000?		
		YARMOUTHIAN (interglacial)		Soil, mature profile of weathering	Important stratigraphic marker
			500,000?		
	Pre-Illinoian	KANSAN* (glacial)		Drift, loess	Glaciers from northeast and northwest covered much of state
			700,000?		
		AFTONIAN* (interglacial)		Soil, mature profile of weathering	(hypothetical)
			900,000?		
		NEBRASKAN* (glacial)		Drift (little known)	Glaciers from northwest invaded western Illinois
			1,600,000 or more		

*Old oversimplified concepts, now known to represent a series of glacial cycles.

(Illinois State Geological Survey, 197

SEQUENCE OF GLACIATIONS AND INTERGLACIAL DRAINAGE IN ILLINOIS

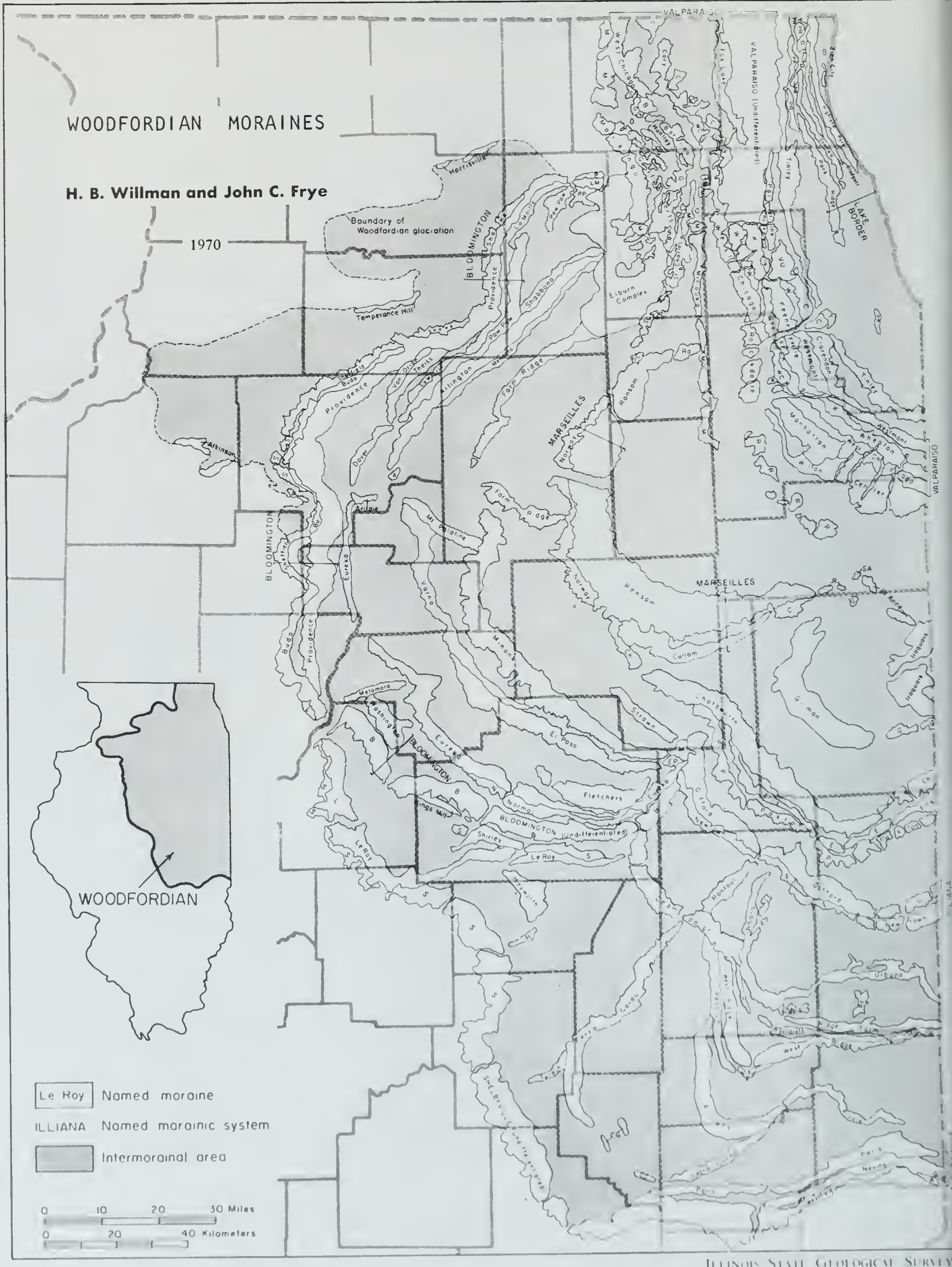


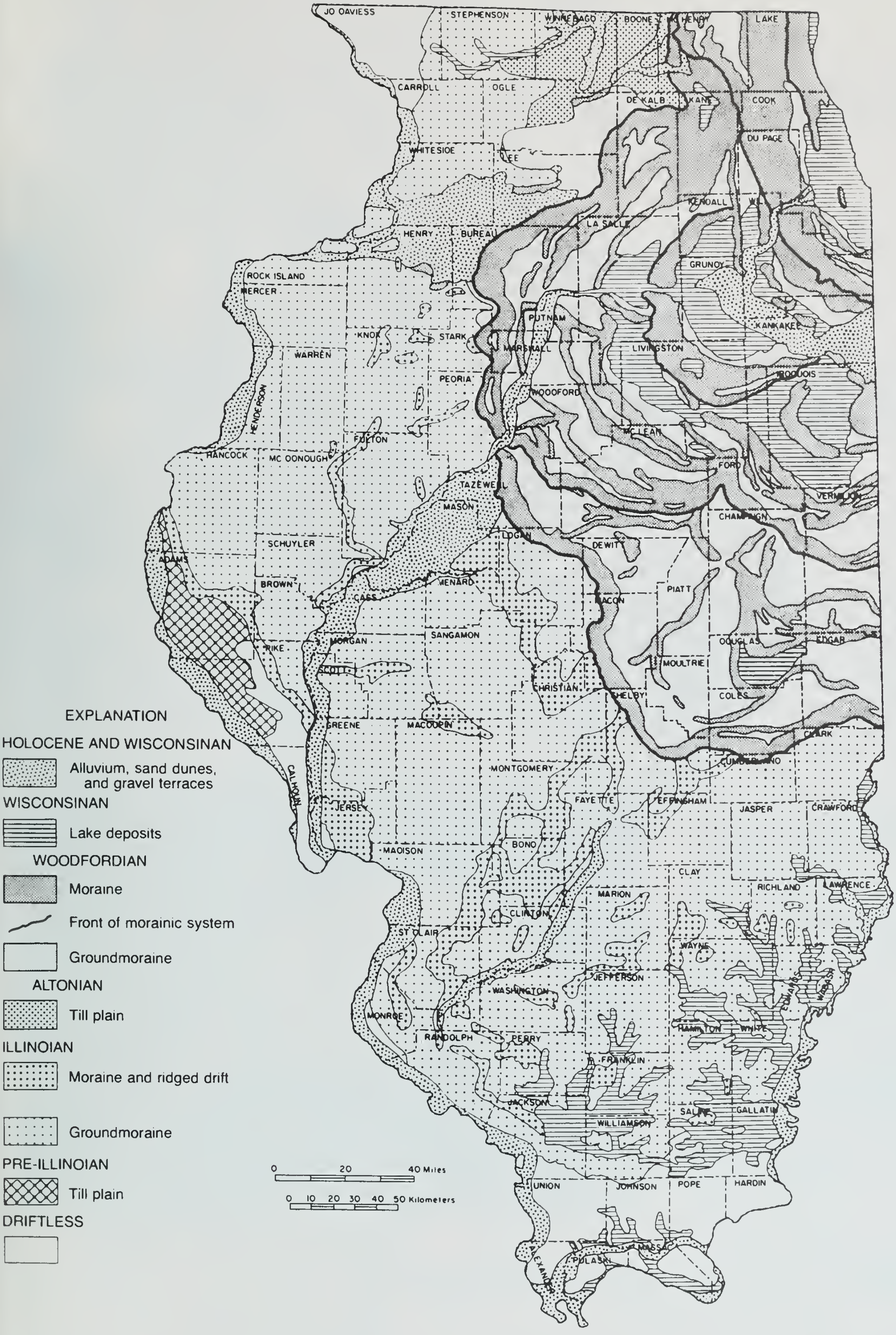
(Modified from Willman and Frye, "Pleistocene Stratigraphy of Illinois," ISGS Bull. 94, fig. 5, 1970.)

WOODFORDIAN MORAINES

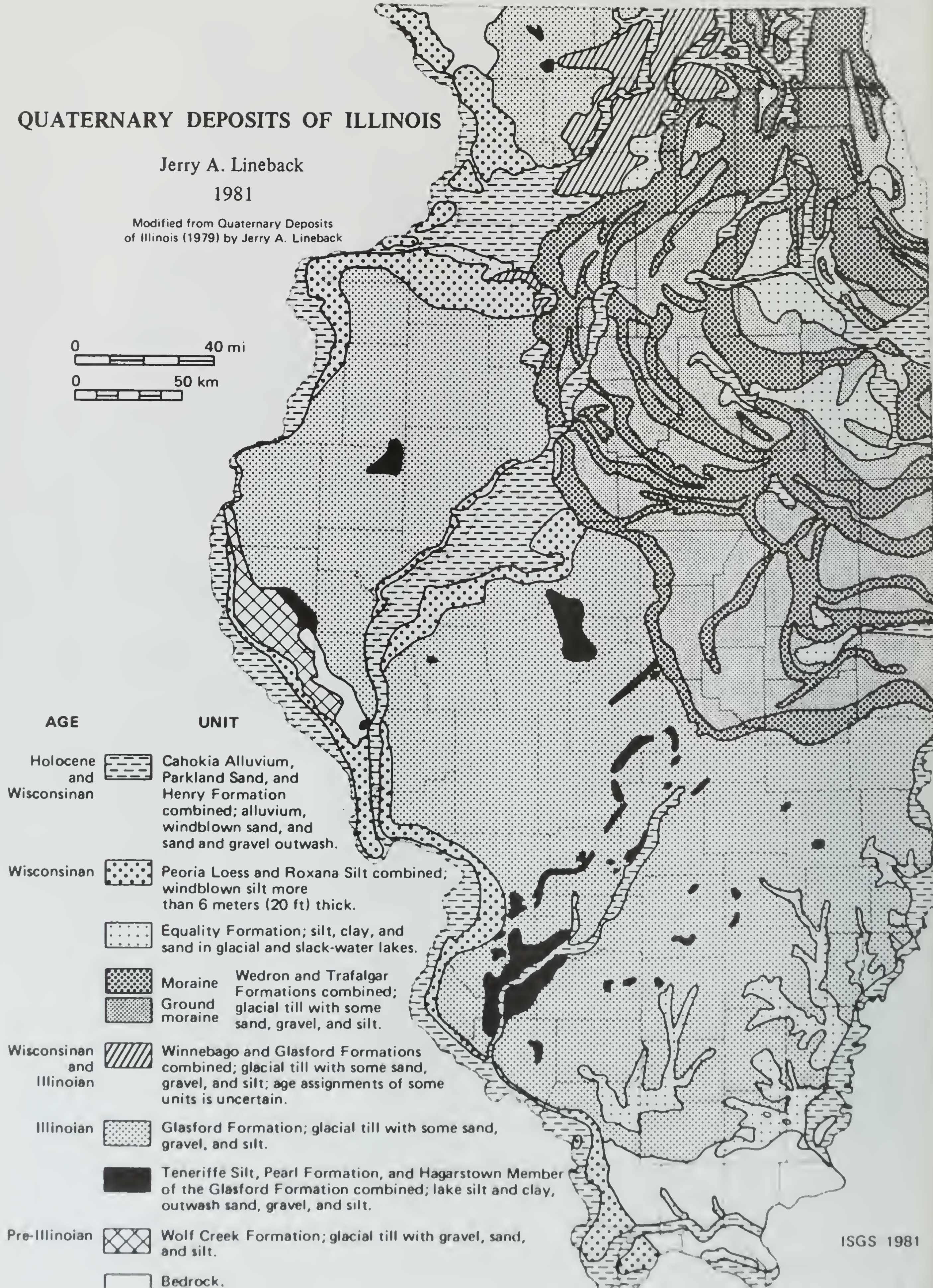
H. B. Willman and John C. Frye

1970





Generalized map of glacial deposits in Illinois (modified from Willman and Frye 1970).


QUATERNARY DEPOSITS OF ILLINOIS
Jerry A. Lineback
1981
Modified from Quaternary Deposits of Illinois (1979) by Jerry A. Lineback
0 40 mi
0 50 km
AGE
UNIT
Holocene and Wisconsinan
Cahokia Alluvium, Parkland Sand, and Henry Formation combined; alluvium, windblown sand, and sand and gravel outwash.
Wisconsinan
Peoria Loess and Roxana Silt combined; windblown silt more than 6 meters (20 ft) thick.
Equality Formation; silt, clay, and sand in glacial and slack-water lakes.
Moraine
Ground moraine
Wedron and Trafalgar Formations combined; glacial till with some sand, gravel, and silt.
Wisconsinan and Illinoian
Winnebago and Glasford Formations combined; glacial till with some sand, gravel, and silt; age assignments of some units is uncertain.
Illinoian
Glasford Formation; glacial till with some sand, gravel, and silt.
Teneriffe Silt, Pearl Formation, and Hagarstown Member of the Glasford Formation combined; lake silt and clay, outwash sand, gravel, and silt.
Pre-Illinoian
Wolf Creek Formation; glacial till with gravel, sand, and silt.
Bedrock.
ISGS 1981

ILLINOIS STATE GEOLOGICAL SURVEY
Urbana, Illinois 61801

GEOGRAM 2
October 1974

ERRATICS ARE ERRATIC

Myrna M. Killey

You may have seen them scattered here and there in Illinois—boulders, some large, some small, lying alone or with a few companions in the corner of a field, at the edge of a road, in someone's yard, or perhaps on a courthouse lawn or schoolyard. Many of them seem out of place, like rough, alien monuments in the stoneless, grassy knolls and prairies of our state. Some—the colorful and glittering granites, banded gneisses, and other intricately veined and streaked igneous and metamorphic rocks--are indeed foreign rocks, for they came from Canada and the states north of us. Others—gray and tan sedimentary rocks—are native rocks and may be no more than a few miles from their place of origin. All of these rocks are glacial boulders that were moved to their present sites by massive ice sheets that flowed across our state. If these boulders are unlike the rocks in the quarries and outcrops in the region where they are found, they are called erratics.

The continental glaciers of the Great Ice Age scoured and scraped the land surface as they advanced, pushing up chunks of bedrock and grinding them against each other or along the ground surface as the rock-laden ice sheets pushed southward. Hundreds of miles of such grinding, even on such hard rocks as granite, eventually rounded off the sharp edges of these passengers in the ice until they became the rounded, irregular boulders we see today. Although we do not know the precise manner in which erratics reached their present isolated sites, many were probably dropped directly from the melting front of a glacier. Others may have been rafted to their present resting places by icebergs on ancient lakes or on the floodwaters of some long-vanished stream as it poured from a glacier. Still others, buried in the glacial deposits, could have worked their way up to the land surface as the surrounding loose soil repeatedly froze and thawed. When the freezing ground expands, pieces of rock tend to be pushed upward, where they are more easily reached by the farmer's plow and also more likely to be exposed by erosion.

An eight-foot boulder of pink granite left by a glacier in the bed of a creek about 5 miles southwest of Alexis, Warren County, Illinois. (From ISGS Bulletin 57, 1929.)

Generally speaking, erratics found northeast of a line drawn from Freeport in Stephenson County, southward through Peoria, and then southeastward through Shelbyville to Marshall at the east edge of the state were brought in by the last glacier to enter Illinois. This glaciation, called the Wisconsinan, spread southwestward into Illinois from a center in eastern Canada, reaching our state about 75,000 years ago and (after repeated advances and retreats of the ice margin) melting from the state about 12,500 years ago. Erratics to the west or south of the great arc outlined above were brought in by a much older glacier, the Illinoian, which spread over most of the state about 300,000 to 175,000 years ago. Some erratics were brought in by even older glaciers that came from the northwest.

You may be able to locate some erratics in your neighborhood. Sometimes it is possible to tell where the rock originally came from by determining the kind of rock it is. A large boulder of granite, gneiss, or other igneous or metamorphic rock may have come from the Canadian Shield, a vast area in central and eastern Canada where rocks of Precambrian age (more than 600 million years old) are exposed at the surface. Some erratics containing flecks of copper were probably transported here from the "Copper Range" of the upper peninsula of Michigan. Large pieces of copper have been found in glacial deposits of central and northern Illinois. Light gray to white quartzite boulders with beautiful, rounded pebbles of red jasper came from a very small outcrop area near Bruce Mines, Ontario, Canada. Purplish pieces of quartzite, some of them banded, probably originated in the Baraboo Range of central Wisconsin. Most interesting of all are the few large boulders of Canadian tillite. Tillite is lithified (hardened into rock) glacial till deposited by a Precambrian glacier many millions of years older than the ones that invaded our state a mere few thousand years ago. Glacial till is an unsorted and unlayered mixture of clay, sand, gravel, and boulders that vary widely in size and shape. Tillite is a gray to greenish gray rock containing a mixture of grains of different sizes and scattered pebbles of various types and sizes.

Many erratics are of notable size and beauty, and in parts of Illinois they are commonly used in landscaping. Some are used as monuments in courthouse squares, in parks, or along highways. Many are marked with metal plaques to indicate an interesting historical spot or event. Keep an eye out for erratics. There may be some of these glacial strangers in your neighborhood that would be interesting to know.

 GEOGRAM 5
October 1975

ANCIENT DUST STORMS IN ILLINOIS

Myrna M. Killey

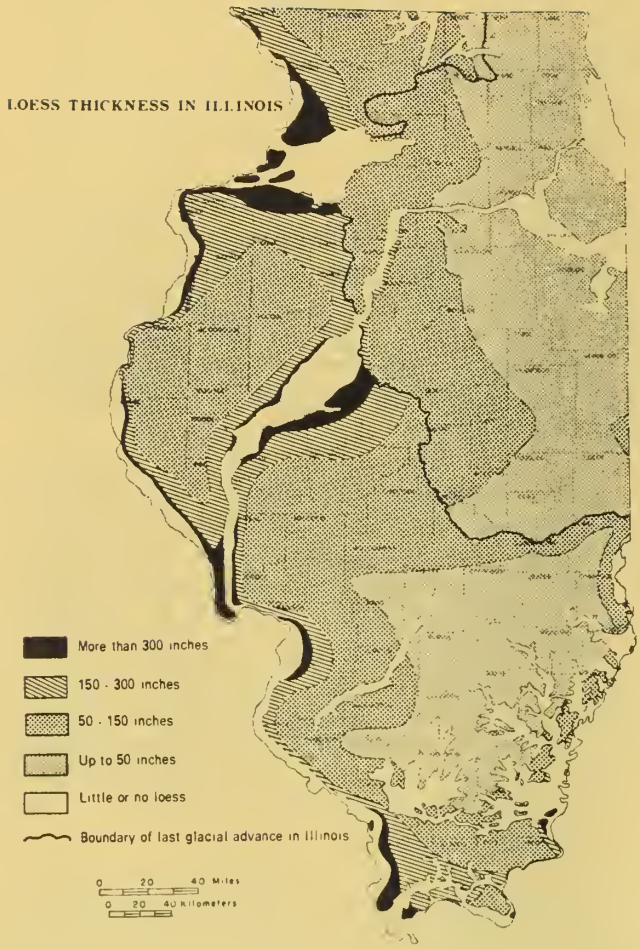
Fierce dust storms whirled across Illinois long before human beings were here to record them. Where did all the dust come from? Geologists have carefully put together clues from the earth itself to get the story. As the glaciers of the Great Ice Age scraped and scoured their way southward across the landscape from Canada, they moved colossal amounts of rock and earth. Much of the rock ground from the surface was kneaded into the ice and carried along, often for hundreds of miles. The glaciers acted as giant grist mills, grinding much of the rock and earth to "flour"—very fine dust-sized particles.

During the warm seasons, water from the melting ice poured from the glacier front, laden with this rock flour, called silt. In the cold months the meltwater stopped flowing and the silt was left along the channels the water had followed, where it dried out and became dust. Strong winds picked up the dust, swept it from the floodplains, and carried it to adjacent uplands. There the forests along the river valleys trapped the dust, which became part of the moist forest soil. With each storm more material accumulated until the high bluffs adjacent to major rivers were formed. The dust deposits are thicker along the eastern sides of the valleys than they are on the western sides, a fact from which geologists deduce that the prevailing winds of that time blew from west to east, the same direction as those of today. From such clues geologists conclude that the geologic processes of the past were much like those of today.

The deposits of windblown silt are called loess (rhymes with "bus"). Loess is found not only in the areas once covered by the glaciers but has been blown into the nonglaciated areas. The glaciers, therefore, influenced the present land surface well beyond the line of their farthest advance.

Loess has several interesting characteristics. Its texture is so fine and uniform that it can easily be identified in roadcuts—and because it blankets such a vast area many roads are cut through it. Even more noticeable is its tendency to stand in vertical walls. These steep walls develop as the loess drains and becomes tough, compact, and massive, much like a rock. Sometimes cracks develop in the loess, just as they do in massive limestones and sandstones. Loess makes good highway banks if it is cut vertically. A vertical cut permits maximum drainage because little surface is exposed to rain, and rainwater tends to drain straight down through it to the rock underneath. If the bank is cut at an angle more water soaks in, which causes the loess to slump down. Along Illinois roads the difference between a loess roadcut and one in ordinary glacial till is obvious. The loess has a very uniform texture, while the till is composed of a random mixture of rock debris, from clay and silt through cobbles and boulders.

Many loess deposits are worth a close look. Through a 10-power hand lens separate grains can be seen, among them many clear, glassy, quartz grains. Some loess deposits contain numerous rounded, lumpy stones called concretions. Their formation began when water percolating through the loess dissolved tiny



limestone grains. Some of the dissolved minerals later became solid again, gathering around a tiny nucleus or along roots to form the lumpy masses. A few such concretions are shaped roughly like small dolls and, from this resemblance, are called "loess kindchen," a German term meaning "loess children." They may be partly hollow and contain smaller lumps that make them rattle when shaken.

Fossil snails can be found in some loess deposits. The snails lived on the river bluffs while the loess was being deposited and were buried by the dust. When they are abundant, they are used to determine how old the loess is. The age is found by measuring the amount of radioactive carbon in the calcium carbonate of their shells.

Some of the early loess deposits were covered by new layers of loess following later glacial invasions. Many thousands of years passed between the major glacial periods, during which time the climate was as warm as that of today. During the warm intervals, the surface of the loess and other glacial deposits was exposed to weather. Soils developed on most of the terrain, altering the composition, color, and texture of the glacial material. During later advances of the ice, some of these soils were destroyed, but in many places they are preserved under the younger sediments. Such ancient buried soils can be used to determine when the materials above and below them were laid down by the ice and what changes in climate took place.

The blanket of loess deposited by the ancient dust storms forms the parent material of the rich, deep soils that today are basic to the state's agriculture. A soil made of loess crumbles easily and has great moisture-holding capacity. It also is free from rocks that might complicate cultivation. Those great dust storms that swirled over the land many thousands of years ago thus endowed Illinois with one of its greatest resources, its highly productive soil.

DEPOSITIONAL HISTORY OF THE PENNSYLVANIAN ROCKS IN ILLINOIS

At the close of the Mississippian Period, about 310 million years ago, the sea withdrew from the Midcontinent region. A long interval of erosion that took place early in Pennsylvanian time removed hundreds of feet of the pre-Pennsylvanian strata, completely stripping them away and cutting into older rocks over large areas of the Midwest. Ancient river systems cut deep channels into the bedrock surface. Later, but still during early Pennsylvanian (Morrowan) time, the sea level started to rise; the corresponding rise in the base level of deposition interrupted the erosion and led to filling the valleys in the erosion surface with fluvial, brackish, and marine sands and muds.

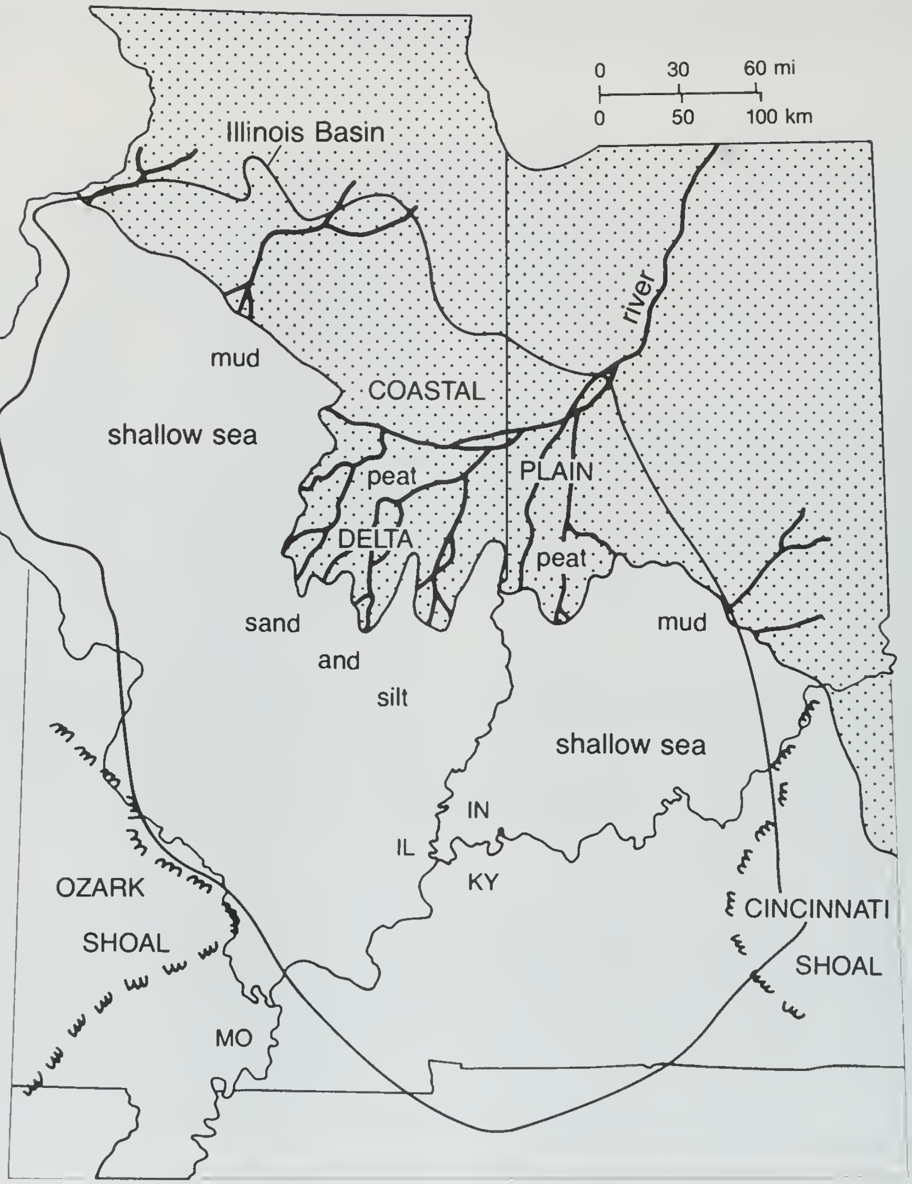
Depositional conditions in the Illinois Basin during the Pennsylvanian Period were somewhat similar to those of the preceding Chesterian (late Mississippian) time. A river system flowed southwestward across a swampy lowland, carrying mud and sand from highlands to the northeast. This river system formed thin but widespread deltas that coalesced into a vast coastal plain or lowland that prograded (built out) into the shallow sea that covered much of present-day Illinois (see paleogeographic map, next page). As the lowland stood only a few feet above sea level, slight changes in relative sea level caused great shifts in the position of the shoreline.

During most of Pennsylvanian time, the Illinois Basin gradually subsided; a maximum of about 3000 feet of Pennsylvanian sediments are preserved in the basin. The locations of the delta systems and the shoreline of the resulting coastal plain shifted, probably because of worldwide sea level changes, coupled with variation in the amounts of sediments provided by the river system and local changes in basin subsidence rates. These frequent shifts in the coastline position caused the depositional conditions at any one locality in the basin to alternate frequently between marine and nonmarine, producing a variety of lithologies in the Pennsylvanian rocks (see lithology distribution chart).

Conditions at various places on the shallow sea floor favored the deposition of sand, lime mud, or mud. Sand was deposited near the mouths of distributary channels, where it was reworked by waves and spread out as thin sheets near the shore. Mud was deposited in quiet-water areas — in delta bays between distributaries, in lagoons behind barrier bars, and in deeper water beyond the nearshore zone of sand deposition. Limestone was formed from the accumulation of limy parts of plants and animals laid down in areas where only minor amounts of sand and mud were being deposited. The areas of sand, mud, and limy mud deposition continually changed as the position of the shoreline changed and as the delta distributaries extended seaward or shifted their positions laterally along the shore.

Nonmarine sand, mud, and lime mud were deposited on the coastal plain bordering the sea. The nonmarine sand was deposited in delta distributary channels, in river channels, and on the broad floodplains of the rivers. Some sand bodies 100 or more feet thick were deposited in channels that cut through the underlying rock units. Mud was deposited mainly on floodplains. Some mud and freshwater lime mud were deposited locally in fresh-water lakes and swamps.

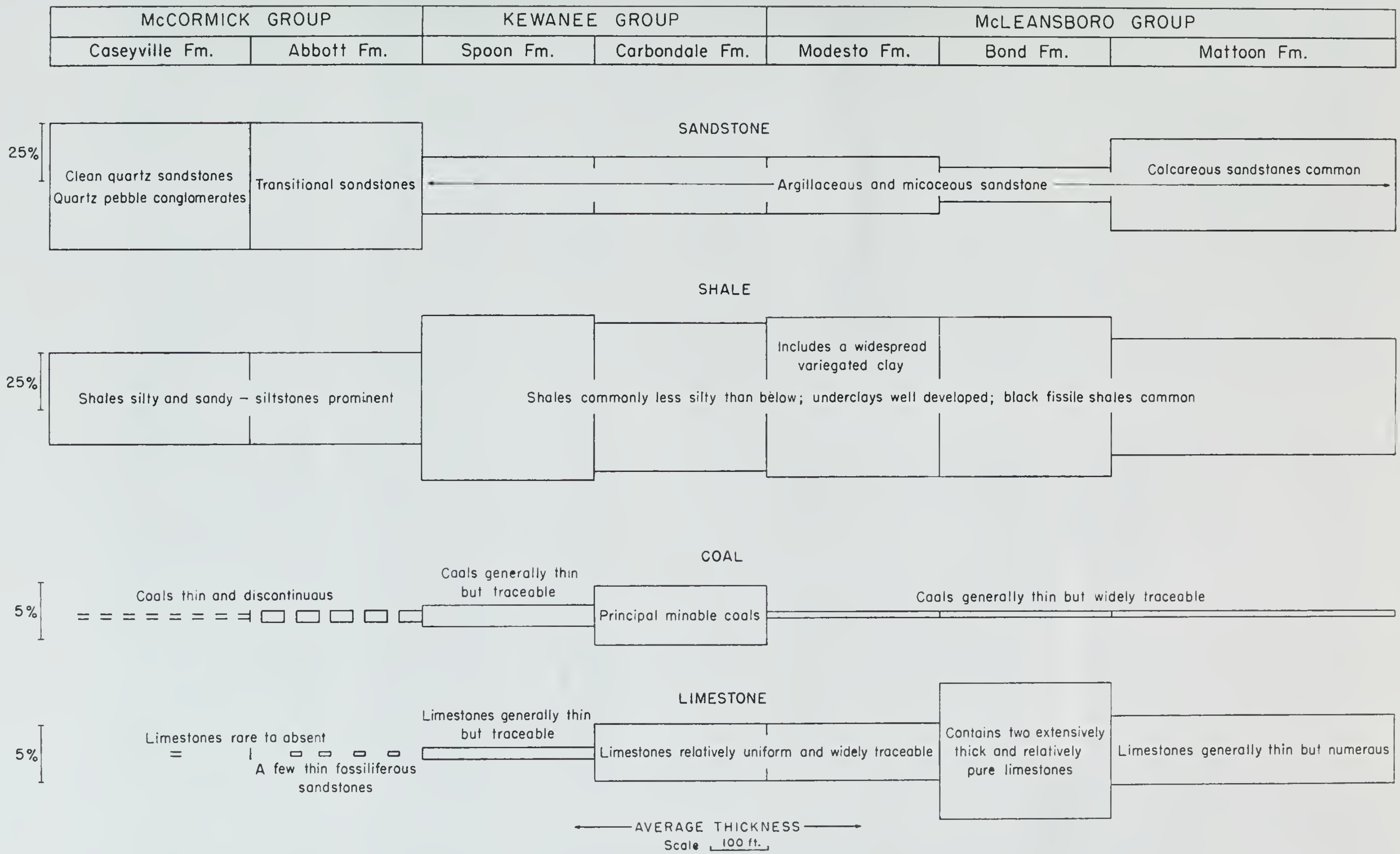
Beneath the quiet water of extensive swamps that prevailed for long intervals on the emergent coastal lowland, peat was formed by accumulation of plant material. Lush forest vegetation covered the region; it thrived in the warm, moist Pennsylvanian-age climate. Although the origin of the underclays beneath the coal is not precisely known, most evidence indicates that they were deposited in the swamps as slackwater mud before the accumulation of much plant debris. The clay underwent modification to become the soil upon which the lush vegetation grew in the swamps. Underclay frequently contains plant roots and rootlets that appear to be in their original places. The vast swamps were the culmination of nonmarine deposition. Resubmergence of the borderlands by the sea interrupted nonmarine deposition, and marine sediments were laid down over the peat.



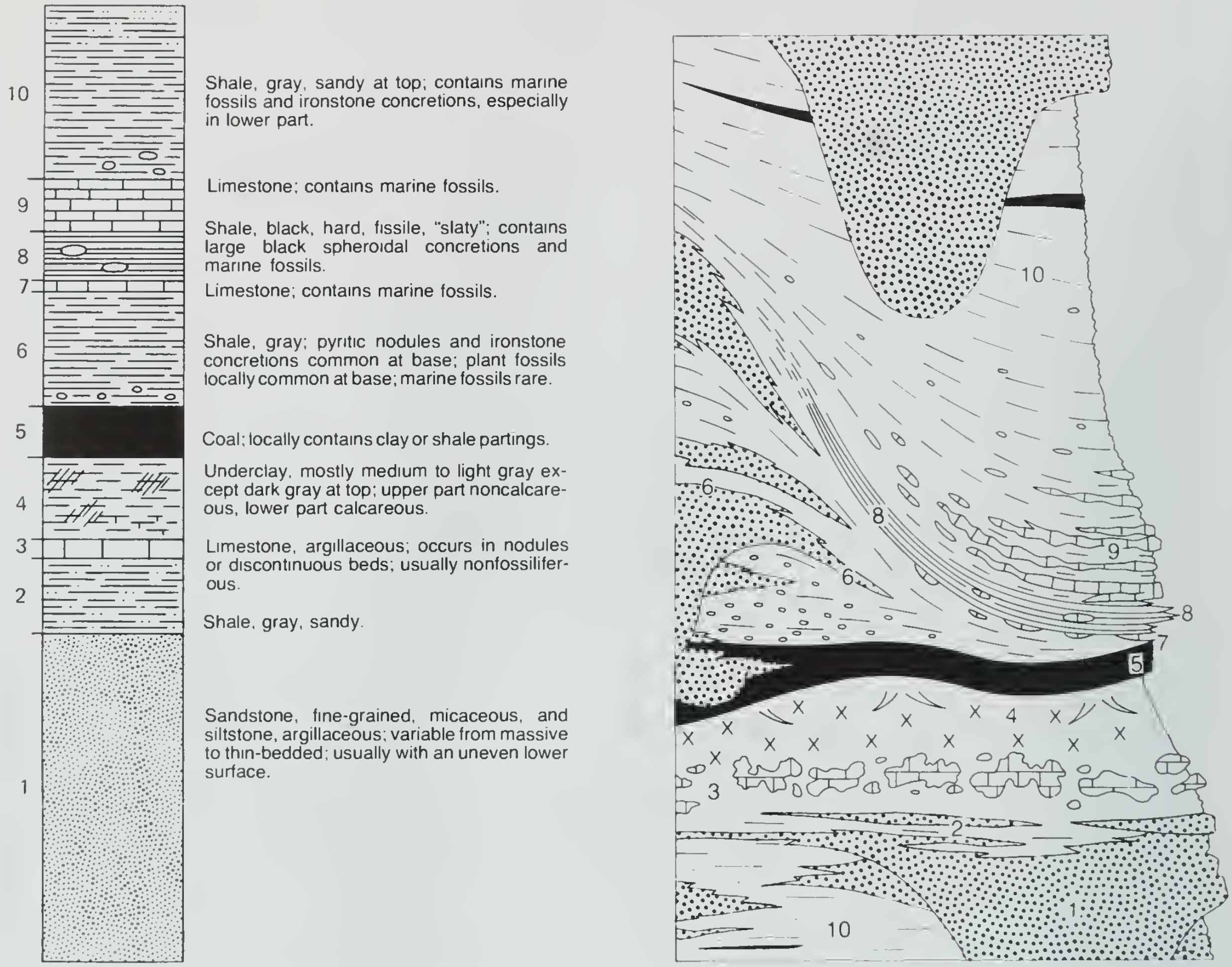
Paleogeography of Illinois-Indiana region during Pennsylvanian time. The diagram shows a Pennsylvanian river delta and the position of the shoreline and the sea at an instant of time during the Pennsylvanian Period.

Pennsylvanian Cyclothems

The Pennsylvanian strata exhibit extraordinary variations in thickness and composition both laterally and vertically because of the extremely varied environmental conditions under which they formed. Individual sedimentary units are often only a few inches thick and rarely exceed 30 feet thick. Sandstones and shales commonly grade laterally into each other, and shales sometimes interfinger and grade into limestones and coals. The underclays, coals, black shales, and some limestones, however, display remarkable lateral continuity for such thin units. Coal seams have been traced in mines, outcrops, and subsurface drill records over areas comprising several states.



General distribution of the four principal lithologies in Pennsylvanian strata of Illinois.



The idealized cyclothem at left (after Willman and Payne, 1942) infers continuous, widespread distribution of individual cyclothem units, at right the model of a typical cyclothem (after Baird and Shabica, 1980) shows the discontinuous nature of many units in a cyclothem.

The rapid and frequent changes in depositional environments during Pennsylvanian time produced regular or cyclical alternations of sandstone, shale, limestone, and coal in response to the shifting shoreline. Each series of alternations, called a cyclothem, consists of several marine and nonmarine rock units that record a complete cycle of marine invasion and retreat. Geologists have determined, after extensive studies of the Pennsylvanian strata in the Midwest, that an "ideally" complete cyclothem consists of ten sedimentary units (see illustration above contrasting the model of an "ideal" cyclothem with a model showing the dynamic relationships between the various members of a typical cyclothem).

Approximately 50 cyclothems have been described in the Illinois Basin but only a few contain all ten units at any given location. Usually one or more are missing because conditions of deposition were more varied than indicated by the "ideal" cyclothem. However, the order of units in each cyclothem is almost always the same: a typical cyclothem includes a basal sandstone overlain by an underclay, coal, black sheety shale, marine limestone, and gray marine shale. In general, the sandstone-underclay-coal-gray shale portion (the lower six units) of each cyclothem is nonmarine: it was deposited as part of the coastal lowlands from which the sea had withdrawn. However, some of the sandstones are entirely or partly marine. The units above the coal and gray shale are marine sediments deposited when the sea advanced over the coastal plain.

Origin of Coal

It is generally accepted that the Pennsylvanian coals originated by the accumulation of vegetable matter, usually in place, beneath the waters of extensive, shallow, fresh-to-brackish swamps. They represent the last-formed deposits of the nonmarine portions of the cyclothems. The swamps occupied vast areas of the coastal lowland, which bordered the shallow Pennsylvanian sea. A luxuriant growth of forest plants, many quite different from the plants of today, flourished in the warm, humid Pennsylvanian climate. (Illinois at that time was near the equator.) The deciduous trees and flowering plants that are common today had not yet evolved. Instead, the jungle-like forests were dominated by giant ancestors of present-day club mosses, horsetails, ferns, conifers, and cycads. The undergrowth also was well developed, consisting of many ferns, fernlike plants, and small club mosses. Most of the plant fossils found in the coals and associated sedimentary rocks show no annual growth rings, suggesting rapid growth rates and lack of seasonal variations in the climate (tropical). Many of the Pennsylvanian plants, such as the seed ferns, eventually became extinct.

Plant debris from the rapidly growing swamp forests — leaves, twigs, branches, and logs — accumulated as thick mats of peat on the floors of the swamps. Normally, vegetable matter rapidly decays by oxidation, forming water, nitrogen, and carbon dioxide. However, the cover of swamp water, which was probably stagnant and low in oxygen, prevented oxidation, and any decay of the peat deposits was due primarily to bacterial action.

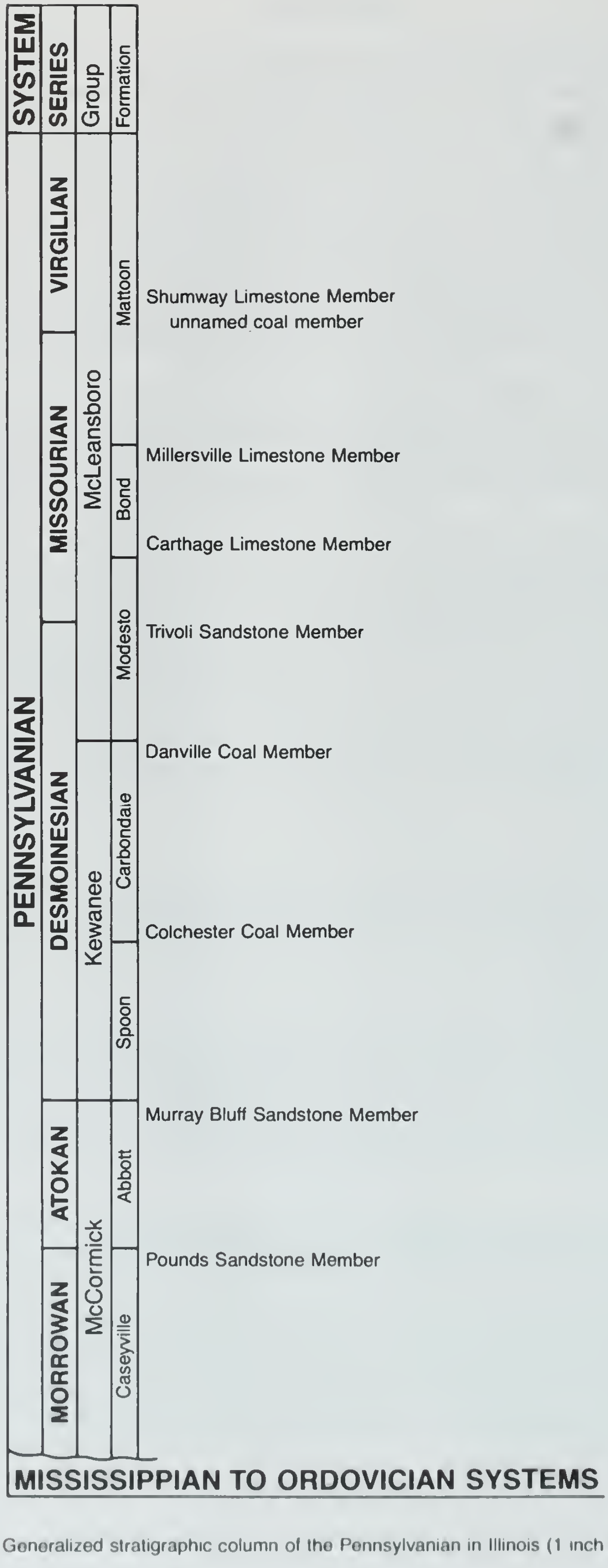
The periodic invasions of the Pennsylvanian sea across the coastal swamps killed the Pennsylvanian forests, and the peat deposits were often buried by marine sediments. After the marine transgressions, peat usually became saturated with sea water containing sulfates and other dissolved minerals. Even the marine sediments being deposited on the top of the drowned peat contained various minerals in solution, including sulfur, which further infiltrated the peat. As a result, the peat developed into a coal that is high in sulfur. However, in a number of areas, nonmarine muds, silts, and sands from the river system on the coastal plain covered the peat where flooding broke through levees or the river changed its coarse. Where these sediments (unit 6 of the cyclothem) are more than 20 feet thick, we find that the coal is low in sulfur, whereas coal found directly beneath marine rocks is high in sulfur. Although the seas did cover the areas where these nonmarine, fluvial sediments covered the peat, the peat was protected from sulfur infiltration by the shielding effect of these thick fluvial sediments.

Following burial, the peat deposits were gradually transformed into coal by slow physical and chemical changes in which pressure (compaction by the enormous weight of overlying sedimentary layers), heat (also due to deep burial), and time were the most important factors. Water and volatile substances (nitrogen, hydrogen, and oxygen) were slowly driven off during the coal-forming ("coalification") process, and the peat deposits were changed into coal.

Coals have been classified by ranks that are based on the degree of coalification. The commonly recognized coals, in order of increasing rank, are (1) brown coal or lignite, (2) sub-bituminous, (3) bituminous, (4) semibituminous, (5) semianthracite, and (6) anthracite. Each increase in rank is characterized by larger amounts of fixed carbon and smaller amounts of oxygen and other volatiles. Hardness of coal also increases with increasing rank. All Illinois coals are classified as bituminous.

Underclays occur beneath most of the coals in Illinois. Because underclays are generally unstratified (unlayered), are leached to a bleached appearance, and generally contain plant roots, many geologists consider that they represent the ancient soils on which the coal-forming plants grew.

The exact origin of the carbonaceous black shale that occurs above many coals is uncertain. Current thinking suggests that the black shale actually represents the deepest part of the marine transgression. Maximum transgression of the sea, coupled with upwelling of ocean water and accumulation of mud and animal remains on an anaerobic ocean floor, led to the deposition of black organic mud over vast areas stretching from Texas to Illinois. Deposition occurred in quiet-water areas where the very fine-grained iron-rich



Generalized stratigraphic column of the Pennsylvanian in Illinois (1 inch = approximately 250 feet).

mud and finely divided plant debris were washed in from the land. Most of the fossils found in black shale represent planktonic (floating) and nektonic (swimming) forms — not benthonic (bottom-dwelling) forms. The depauperate (dwarf) fossil forms sometimes found in black shale formerly were thought to have been forms that were stunted by toxic conditions in the sulfide-rich, oxygen-deficient water of the lagoons. However, study has shown that the "depauperate" fauna consists mostly of normal-size individuals of species that never grew any larger.

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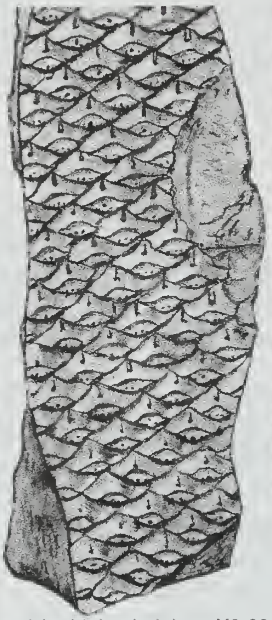
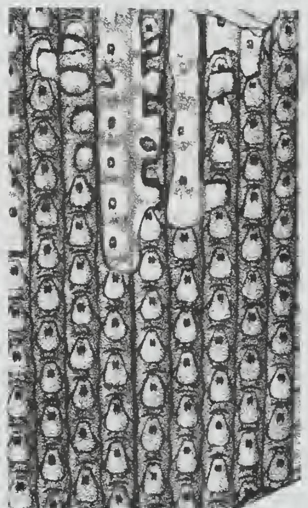
Common Pennsylvanian plants: lycopods, sphenophytes, and ferns

Lepidodendron aculeatum X0.8



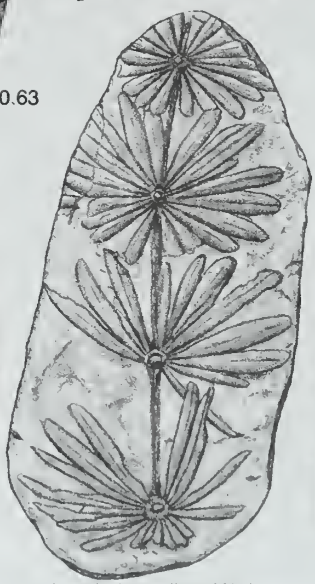
Lepidophloios laricinus X0.63



Sigillaria mammilaris X0.5

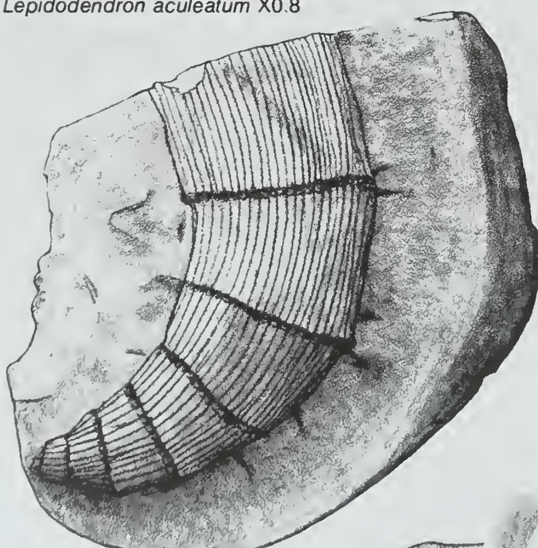
Stigmaria ficoides X0.32

Lepidostrobus ovatifolius X0.8

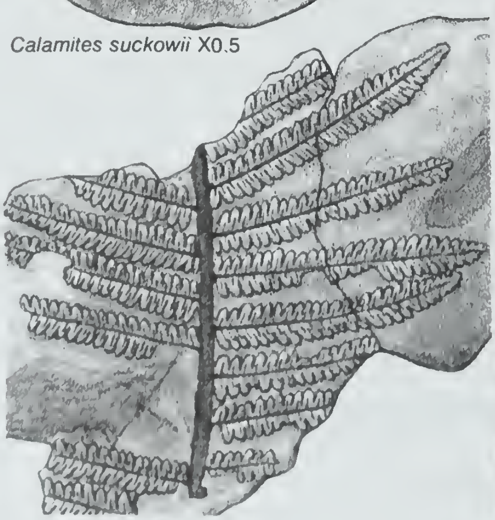


Annularia stellata X0.63

Sphenophyllum cuneifolium X0.4

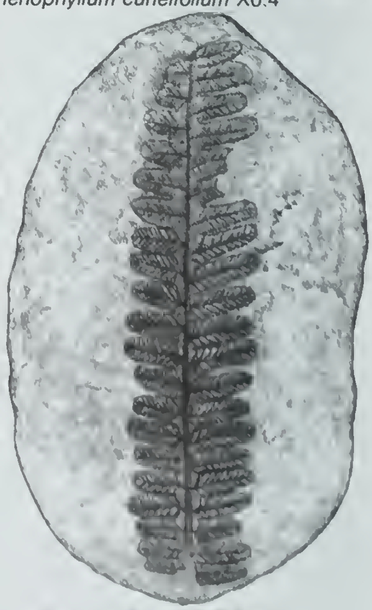


Calamites suckowii X0.5



Pecopteris sp X0.32

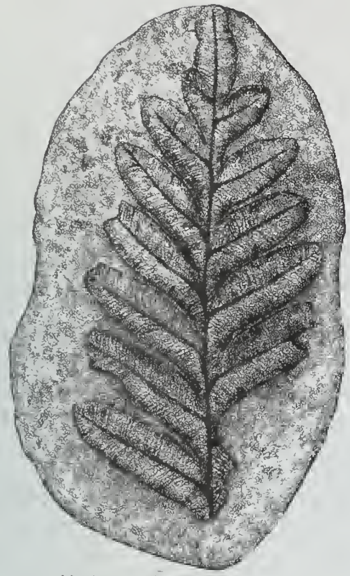
Pecopteris miltonii X2 0



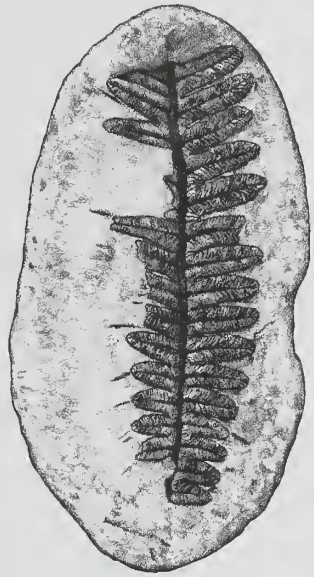
Pecopteris hemitelioides X1.0

J R Jennings, ISGS

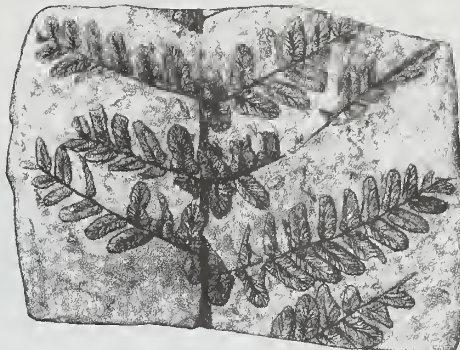
Common Pennsylvanian plants: seed ferns and cordaiteans



Alethopteris serlii X0.63



Alethopteris ambigua X0.63

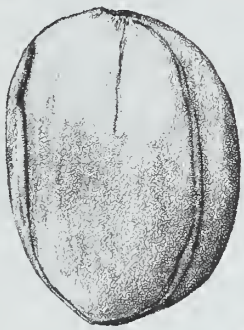


Neuropteris rarinervis X0.5

Mariopteris nervosa X0.8

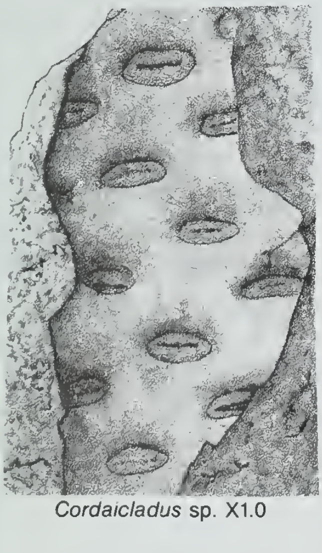
Neuropteris scheuchzeri X0.63

Sphenopteris rotundiloba X0.8

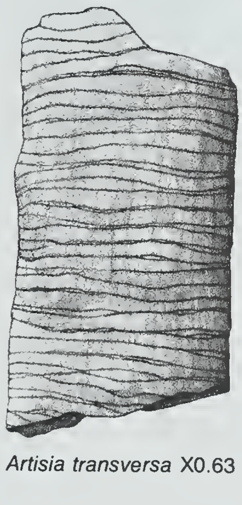


Trigonocarpus parkinsonii X1.25

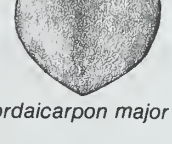
Cordaites principalis X0.63



Cordaicladus sp. X1.0



Artisia transversa X0.63



Cordaicarpon major X2.0

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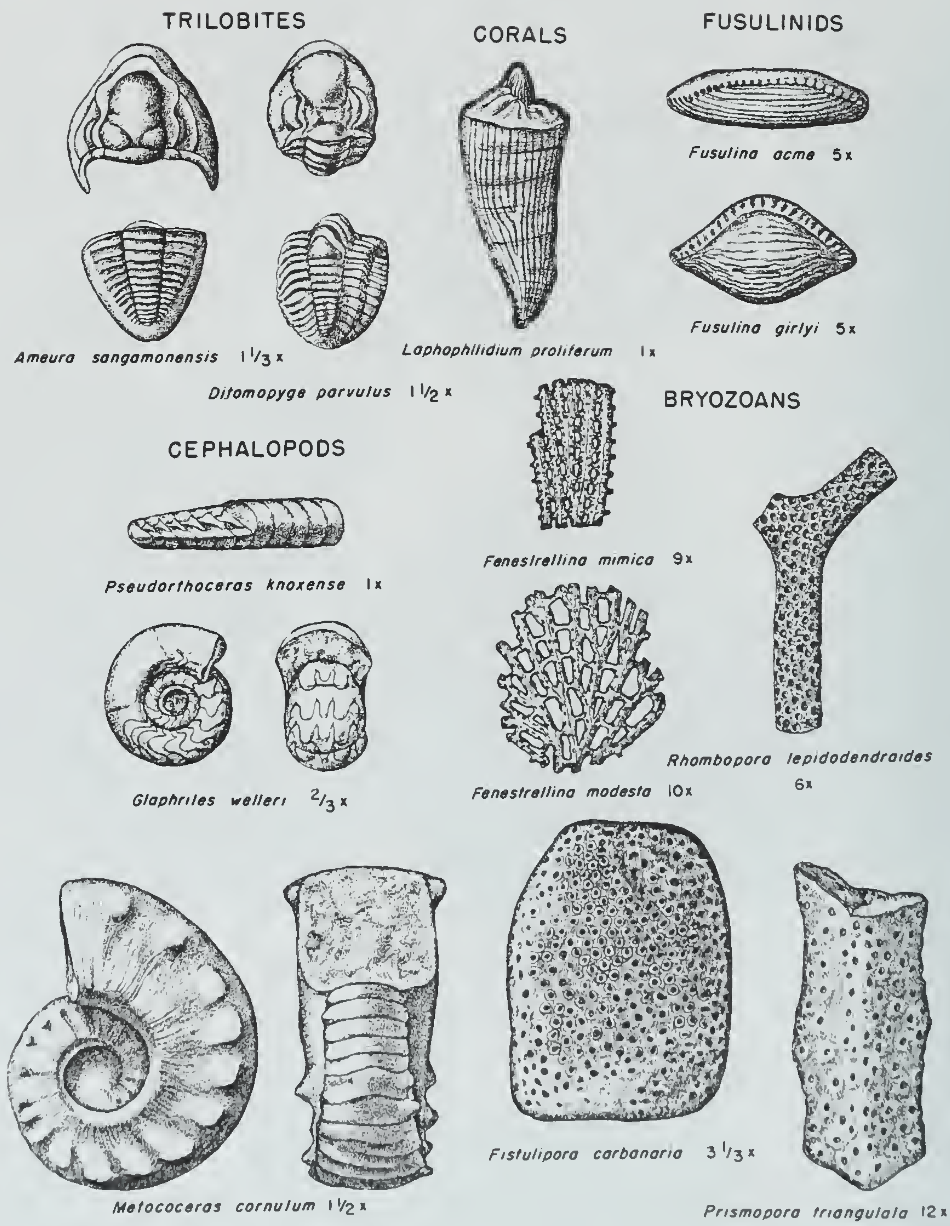

TRILOBITES
CORALS
FUSULINIDS
Fusulina acme 5x
Fusulina girlyi 5x
Ameura sangamonensis 1 1/3 x
Laphophllidium proliferum 1x
Ditomopyge parvulus 1 1/2 x
BRYOZOANS
CEPHALOPODS
Pseudorthoceras knoxense 1x
Fenestrellina mimica 9x
Rhombopora lepidodendraides 6x
Glaphrites welleri 2/3 x
Fenestrellina modesta 10x
Fistulipora carbanaria 3 1/3 x
Metococeras cornulum 1 1/2 x
Prismopora triangulata 12x

PELECYPODS

Nucula (Nuculopsis) girtyi 1x

Edmania ovata 2x

Astartella concentrica 1x

Dunbarella knighti 1 1/2 x

Cardiomorpha missouriensis "Type A" 1x

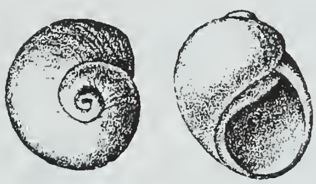
Cardiomorpha missouriensis "Type B" 1 1/2 x

GASTROPODS

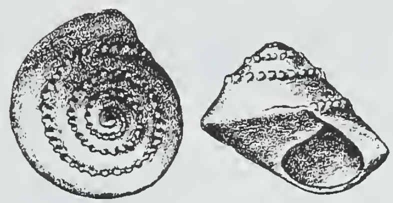
Euphemites carbonarius 1 1/2 x

Trepospira illinoisensis 1 1/2 x

Donaldina robusta 8x



Naticopsis (Jedria) ventricosa 1 1/2 x



Trepospira sphaerulata 1x

Knightites montfortianus 2x

Glabrocingulum (Glabrocingulum) grayvillense 3x

BRACHIOPODS

Juresania nebrascensis 2/3 x

Wellerella tetrahedra 1 1/2 x

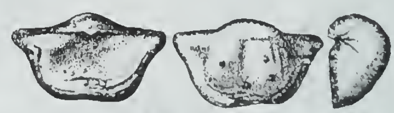
Derbya crassa 1x

Composita argentia 1x

Neospirifer cameratus 1x

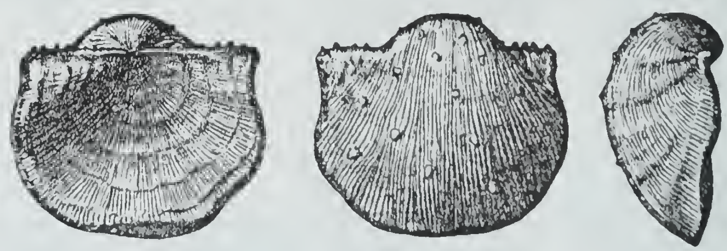
Chonetes granulifer 1 1/2 x

Mesolobus mesolobus var. evampygus 2x

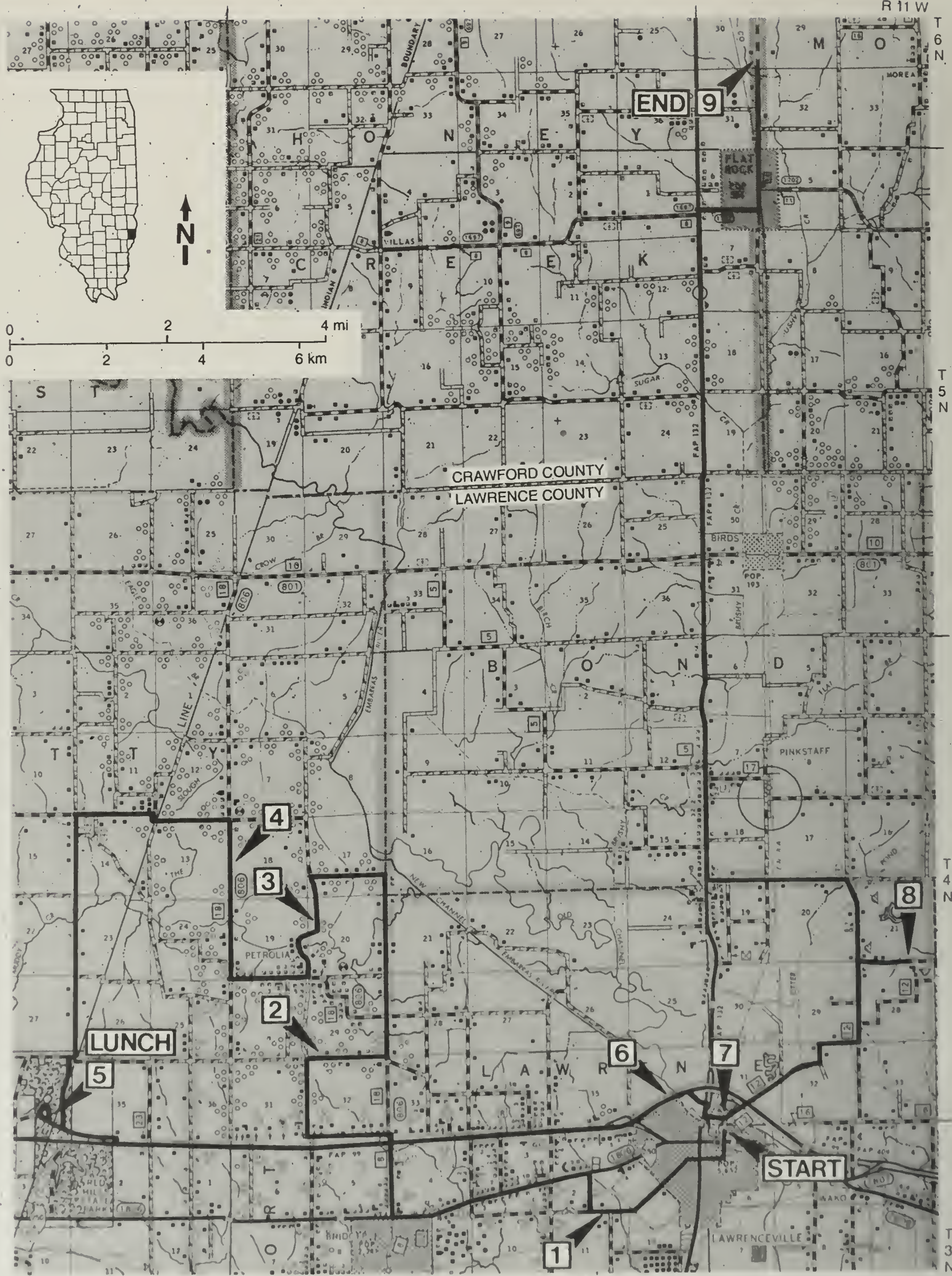


Marginifera splendens 1x

Crurithyris planoconvexa 2x



Linoproductus "cora" 1x



R 11 W
T 6 N
T 5 N
T 4 N
T 3 N
END 9
FLAT ROCK
CRAWFORD COUNTY
LAWRENCE COUNTY
BIRDS
POP. 193
PINKSTAFF
PETROLIA
LUNCH
START
LAWRENCEVILLE
1
2
3
4
5
6
7
8
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2
4 mi
0
2
4
6 km
N